APRIL 1986 VOL. 8 NO. 4

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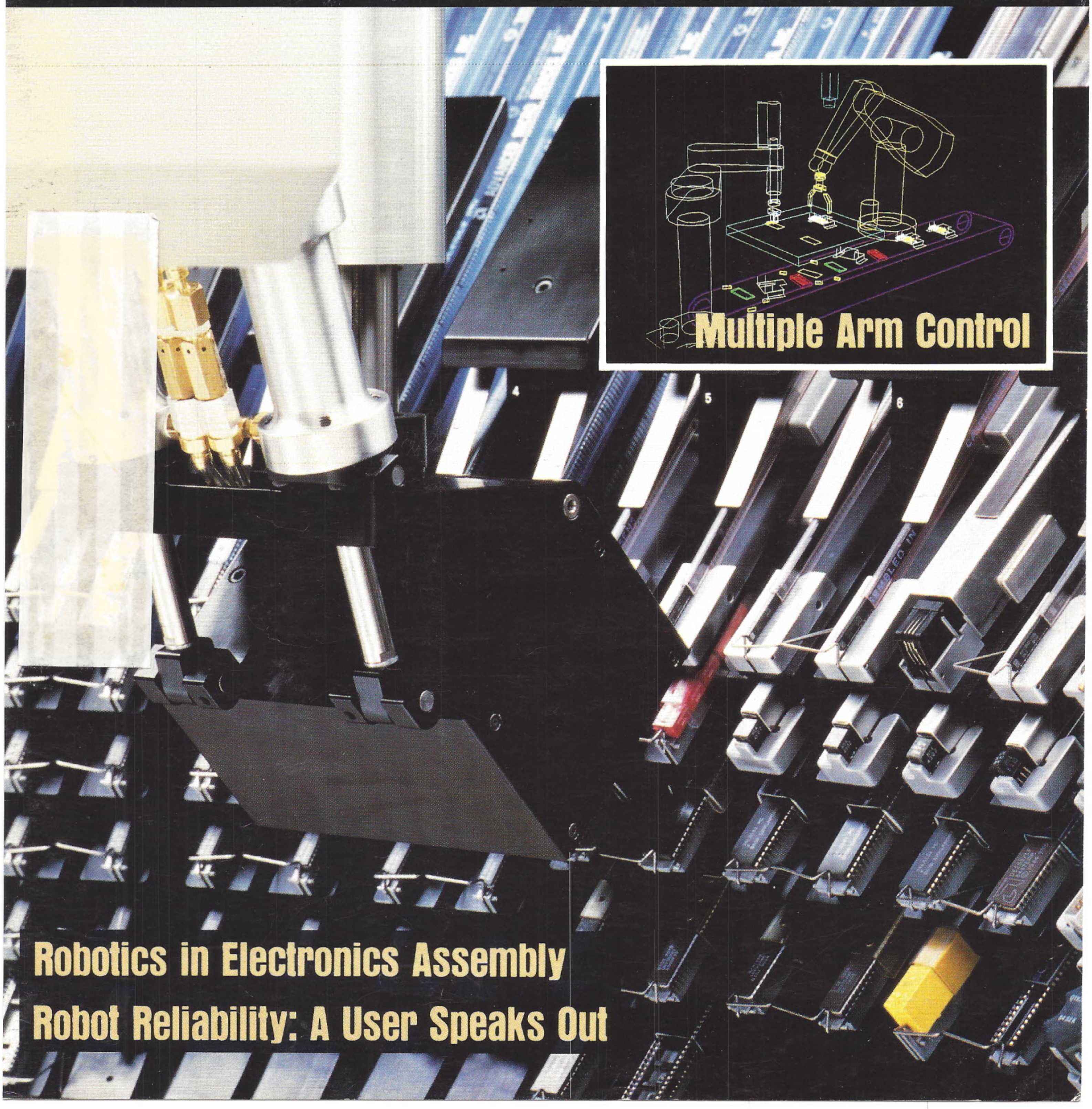
ROBOTICS ENGINEERING

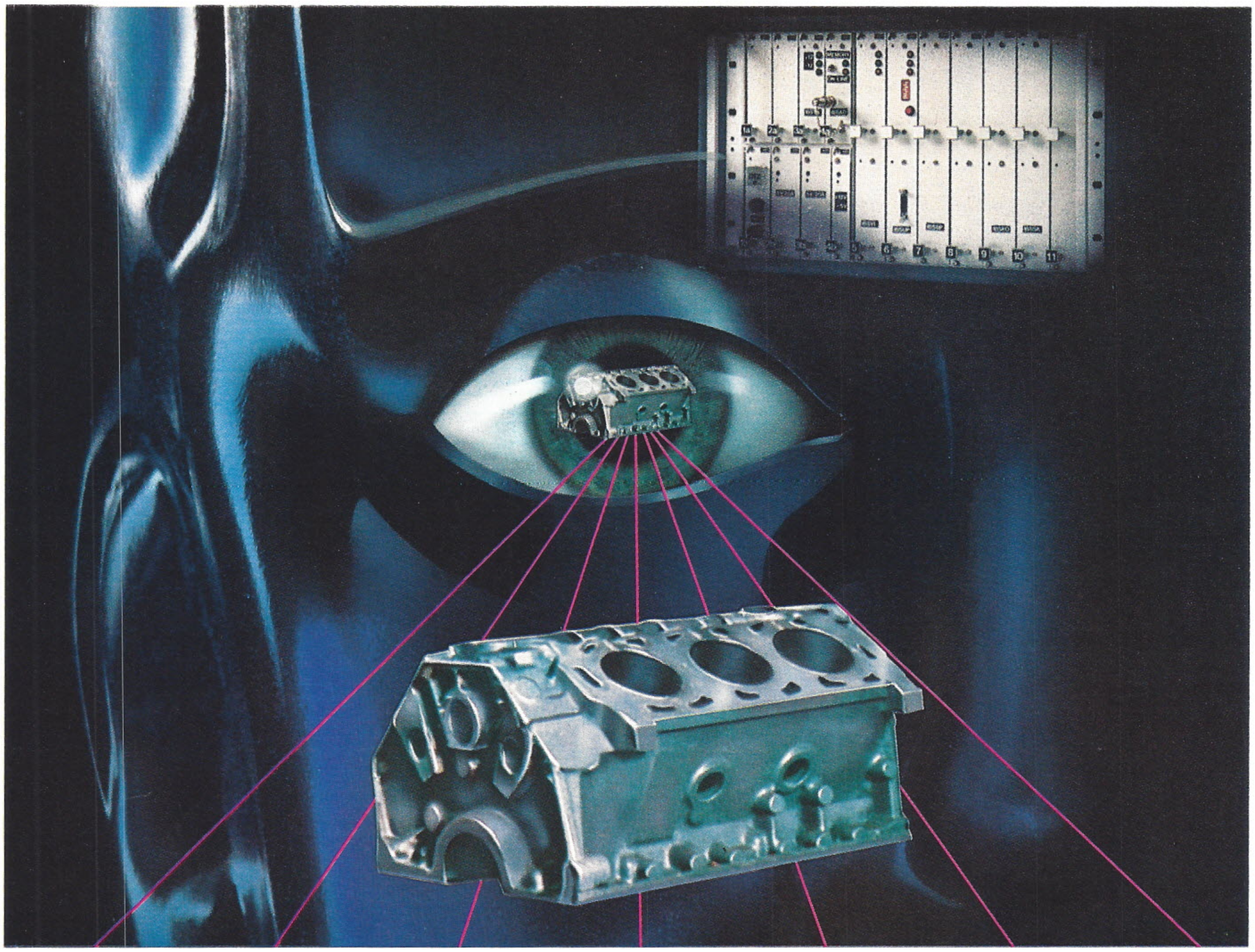
THE JOURNAL OF INTELLIGENT MACHINES



Multiple Arm Control

Robotics in Electronics Assembly

Robot Reliability: A User Speaks Out



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THE JOURNAL OF INTELLIGENT MACHINES

ROBOTICS ENGINEERING

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EDITORIAL

FEATURES

DEPARTMENTS

About the cover: This month's cover photos were provided by Chad Industries and by Silma Incorporated. Silma's CimStation™ (above right) uses computer aided design to create and modify a 3-D model of one or more robotic workcells, write programs, and create computer graphic animation of the robots executing their programs. Chad's Model ECA 1101 parts presentation end effector is shown receiving a mix of standard and nonstandard printed circuit board components, which it will present to the insertion end effector for through-hole placement on the board. See related articles on pages 26 and 30.

Editorial

Robots—The Reliability Issue

BY CARL HELMERS

In an address to the annual meeting of the Robotic Industries Association this January, Robert J. Piccirilli, director of manufacturing engineering at Chrysler, brought to light a growing need: End users of robots must become more actively involved in the design, development, implementation, and, above all, the verification process of robots and robotic systems.

Chrysler's experience, it seems, has not been a happy one. Not one of the some 200 robots of both domestic and foreign manufacture the firm put to its 50-hour and 20-hour testing procedures performed according to manufacturers' specifications. Fifty robots broke down before actual testing began. The causes, Chrysler says, were design and manufacturing defects that came with the robots. (For an in-depth look at the problems Chrysler has identified and the ways the firm plans to solve them, see the articles beginning on pages 6 and 7.)

Chrysler's position is that the end user should be neither surprised nor disappointed by the performance of a new robot—the device should be able to go straight from the receiving platform to the factory floor and do precisely what it was purchased to do immediately upon being set up and plugged in.

A certain amount of leeway must be given when applying any developing technology, because it is only through application that technology can develop. Robots, however, are no longer brand-new; a replacement market has already begun to emerge. And Chrysler, a substantial buyer and user of robotic technology, is saying that enough is enough and has come up with a user-defined specification of acceptable performance. Is there a need for a manufacture-independent organization to gather and provide essential information on comparability and performance of the robots offered in the marketplace?

The RIA, in a laudable attempt to increase its interaction with end user member companies, has announced its intention to strengthen ties with Robotics International of the Society of Manufacturing Engineers. The RIA has also begun to reconsider its definition of a robot, and, according to an RIA spokesman, any new definition created will take into account such technologies as vision and other sensor capabilities, along with automatic guided vehicles and other technologies that were only in their infancy when the current definition was developed. We hope that the RIA's new definition will reflect the fact that the robot, as an intelligent machine, is no longer solely applied to discrete parts manufacturing, that applications now extend into process control and material handling, among other areas.

Chrysler's experience has led to the formulation of one vendor-independent set of verification tests for robotic products. The demand for such testing can hardly be limited to one corporation. We suspect that the entire robot end user industry is calling for the formation of some organization—or movement within an existing organization—to assure the purchasers of industrial robots that they can believe the manufacturers' product brochures and expect what they buy to live up to its billing.

The builders of robots must never forget that solving their customers' needs is paramount to the growth of their own industry. This is especially important in the application of robotics as a necessity for increased productivity, a higher-quality product, and improved human safety conditions. Why else would anyone buy a robot? ■

Calendar

APRIL

1–3. Manufacturing Productivity Conference and Exposition. H. Roe Bartle Hall, Kansas City, MO. Contact: Public Relations Department, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

3–4. Artificial Intelligence—An Applications-Oriented Approach. Contact: Stod Cortelyou, The George Washington University, Washington, DC 20052, telephone (202) 676-6106 or (800) 424-9773.

7. Semiconductor Equipment Communications Standard Seminar. Phoenix, AZ. Contact: Jack Ghiselli, GW Associates, Inc., 645 Mills Ave., Los Altos, CA 94022, telephone (415) 948-2896.

7–10. 1986 IEEE International Conference on Robotics and Automation. San Francisco Hilton & Tower, San Francisco, CA. Contact: Robotics & Automation, c/o Harry Hayman, 738 Whitaker Terrace, Silver Spring, MD 20901, telephone (301) 434-1990.

7–11. IEEE Computer Society Tutorial Week. Orlando Marriott Hotel, Orlando, FL. Contact: Director of Tutorials, IEEE Computer Society, 1730 Massachusetts Ave., N.W., Washington, DC 20036-1903, telephone (202) 371-0101. (To be repeated **12–16** May at the Fairmont Hotel, Dallas, TX; **9–13** June at the Quality Inn Pentagon City, Arlington, VA.)

8–10. Instrumentation '86—Pacific Northwest Conference and Exhibit. Red Lion Inn, Lloyd Center, Portland, OR. Contact: Duane Schroeder, Publicity Chairman, Control Elements, Inc., 1730 S.W. Skyline Blvd., Portland, OR 97221, telephone (503) 297-1533.

8–10. 1986 Test & Measurement World Expo. San Jose Convention Center, San Jose, CA. Contact: Meg Bowen, Conference Director, Test & Measurement World Expo, 199 Wells Ave., Newton, MA 02159, telephone (617) 964-8900.

8–10. 15th Annual International Programmable Controllers Conference and Exposition. Cobo Hall, Detroit, MI. Contact: Carmelita Smirnes, Media Relations Coordinator, Engineering Society of Detroit, 100 Farnsworth Ave., Detroit, MI 48202, telephone (313) 832-5400.

9–12. CommunicAsia 86. World Trade Centre, Singapore. Contact: Gerald G. Kallman, Five Maple Court, Ridgewood, NJ 07450-4431, telephone (201) 652-7070.

9–16. Industrial Automation '86. Independent exhibit sector of Hannover Fair '86, Hannover, West Germany. Contact: Hannover Fairs USA, Inc., PO Box 7066, 103 Carnegie Center, Princeton, NJ 08540, telephone (609) 987-1202.

15–17. First International Conference on Product Design for Assembly. Newport, RI. Contact: Donna White, Conference Registrar, Troy Conferences, 134 W. University Dr., Suite 110, Rochester, MI 48063, telephone (313) 656-2195.

16. Computers and Expert Systems for Welding Operations. Annual Convention of the American Welding Society, Altanta, GA. Contact: Rosalie Brosilow, Editor, *Welding Design & Fabrication*, 1111 Chester Ave., Cleveland, OH 44114, telephone (216) 696-7000.

16–18. Electronic Systems Orientation For Fluid Power Sales Specialists. Milwaukee School of Engineering, Milwaukee, WI. Contact: Cynthia Peck, National Fluid Power Association, 3333 N. Mayfair Rd., Milwaukee, WI 53222, telephone (414) 778-3356.

21–24. ROBOTS '86. McCormick Place, Chicago, IL. Contact: Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

Continued on page 44.

Robotics: A User's Perspective

This material was excerpted from an address to the Robotic Industries Association given by R.J. Piccirilli, Jr. at the RIA's annual meeting on January 30, 1986 in Scottsdale, Arizona. For an expanded discussion of Chrysler's robot performance requirements and its testing program, see the accompanying interview with Richard E. Dauch, beginning on page 7.

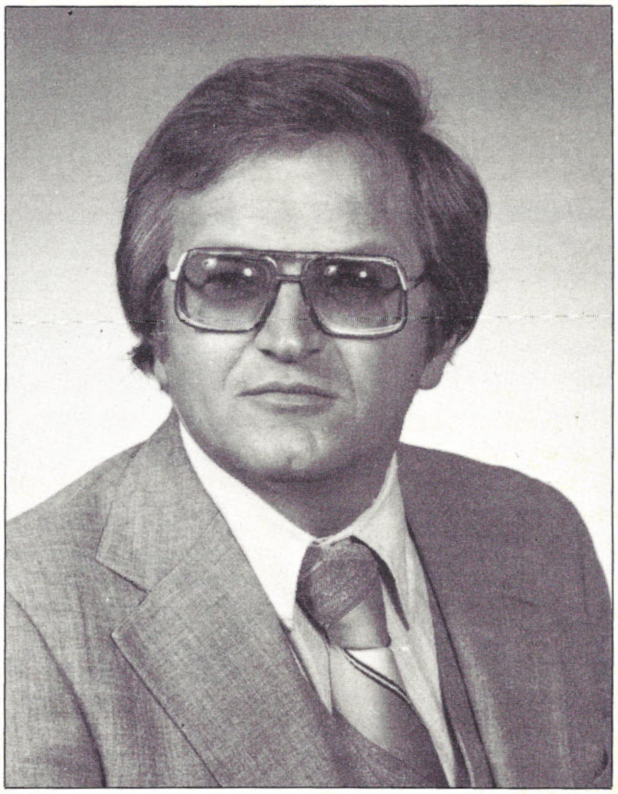
Aggressive application of robotics, along with other actions, has had a dramatic impact on Chrysler's quality and productivity performance. From 1980 to 1985, our quality, as measured by the number of quality defects per 100 vehicles reported by our dealerships, improved by 42 percent.

Quality and productivity go hand-in-hand. Improved quality brought these dramatic improvements in productivity:

- Vehicle production jumped from 4000 to about 8000/day.
- Vehicles produced per employee grew from about 10 to about 19.
- Six stamping plants were compressed into three.
- Steel inventories at stamping plants shrank from 41 days to 9 days.
- Most important, profit generation went from −$10 million/day to +$10 million/day.

These quality and productivity gains came through careful planning and using the four M's of manufacturing—manpower, methods, materials, and machinery. Using robots has been a big factor in attaining these results.

Chrysler must improve its performance still further. We estimate we are still wasting $3.7 billion/year—some 20–25 percent of our sales revenue—because we are not defect-free in our operations. We call it the *cost of quality nonconformance*. In short, this $3.7 billion is the cost of *not doing the job right the first time* throughout the corporation and our supplier corps, including our robot suppliers.



R.J. Piccirilli, Jr., Director of Manufacturing Engineering, Chrysler Corporation.

While still relying on new technologies and processes to raise quality and cut costs, the culture within both Chrysler and its robot suppliers has to change from a "get better" mindset to one that says *no level of defect is acceptable in any operation*. The robot industry is expected to play a major role in helping Chrysler implement this philosophy—through a systematic, step-by-step quality improvement process (QIP) based on four principles:

- The definition of quality is *consistent conformance to requirements*. Everyone must fully understand and conform to the customers' requirements.
- The quality system must stress preventing quality problems rather than detecting problems after the fact.
- The performance standard is to be defect-free.
- The quality measurement will be the cost of quality nonconformance.

We will attack the problem through:

- visible and ongoing management commitment
- local quality-improvement teams
- awareness—sharing experiences and recognizing achievements
- education—all must understand their individual and collective roles in managing the process

Continued on page 9

We Need Reliable, Ready-To-Use Robots, Not Fix-It Later Kits!

An Interview with Richard E. Dauch

Ben Nagler
Advanced Technology Communications
2336 Loyola Road
Cleveland, OH 44118

Trade associations' annual meetings can be nothing more than pep rallies or excuses for tax-deductible vacations at exotic resorts. While attendees at the Robotic Industries Association's annual meeting, held this past January in Scottsdale, Arizona, got both, they also got an earful of complaints from a major robot user—Chrysler Motors.

In a presentation remarkable both for its candor and its detail, Robert J. Piccirilli, Jr., Chrysler Motors' director of manufacturing engineering, first spelled out the importance of reliable robots to his firm's operations and profitability, and then told of shocking failures in robots supplied to them. (Highlights of Piccirilli's remarks appear in the accompanying article.) In a subsequent exclusive interview, Chrysler's Richard E. Dauch, executive vice president of manufacturing, provided cogent insights into other factors making for successful robotic applications.

Richard E. Dauch, Executive Vice President of Manufacturing, Chrysler Corporation.

Why did you choose the Robotic Industries Association's (RIA) annual meeting to publicize your new robot standards?

We, at Chrysler, found we were not getting the repeatability we expected in a robot—as it was expected to accomplish a given task. So I asked my people to tell me what they think quality really is—to see if we, the auto industry, as the customer for 60 percent of the robots being sold, have properly defined to the robot manufacturers what our requirements are. I [also felt we ought to work] with RIA [since it] establishes the industry standards and is also, of course, the promotional arm for the robotics industries. When I got into it, I found that their Standards Committee was not chaired by a user. They have seven [standards] subcommittees, one of which is called "Performance," and none of those seven subcommittees was chaired by a user: they were all chaired by manufacturers of robots! But *who* is the customer? The manufacturer is not the customer: the *user* is the customer.

It is my recommendation that RIA reconsider having a user—especially from [any of] their biggest users, the auto industry, or the electronics industry, or aerospace—chair every single, solitary subcommittee, as well as the Standards Committee itself, so that we can define what is going wrong with these robots that we're presently getting.

Now, our standards are not [just] to get better. Our standards are [that equipment be] *absolutely defect-free*! We do not want any defect in the robot *as we receive it*. We expect it to be fully developed. We expect it properly produced, with proper standards of quality, reliability, performance, and all other standards that RIA as a trade association supports for the robotic industries—because we, the auto industry, are the big user, and as I foresee it, we'll continue to be over 50 percent of the market for the next 10 years.

When you talk to any automation equipment manufacturer, not just robot manufacturers, they all claim to burn in their circuit boards and test their equipment before shipment to prevent so-called "infant mortality" in their products. How, then, can you explain the failures Chrysler has experienced?

I think it's because we, as the customer, had not clearly articulated what our needs were to the robot manufacturers, and I don't believe that the robot manufacturers—and I certainly can't speak for them—were properly articulating their needs to their suppliers or subsuppliers. The net result is the failures in the robots we checked, whereby [there were] drive-motor circuit board failures, electrical failures, overloaded drive mechanisms or other mechanical failures, as well as software problems. These items have been categorized by robot, by manufacturer, by detail, and given out to the manufacturers in the RIA for only one reason: to assist them in making their machinery more reliable, more qualified for us [in] the automotive sector—specifically Chrysler Motors—where we're committed to robots' being very importantly involved in our conversion to factories of the future.

Let me give you a specific example of what I'm getting at. In September, 1984 we put 56 electric robots into the respot welding line in Sterling Heights, Chrysler's most progressive world-class assembly plant as we launched the 1985 Chrysler LeBaron GTS and Dodge Lancer. We've had tremendously good results with those robots—*once they became reliable.*

They were not reliable to begin with?

They were not reliable, but the manufacturer, Cincinnati Milacron, stood well behind their reputation and corrected the problem—but I call that the "pound of cure" instead of the "ounce of prevention" [of] having fully developed the robot and met the requirements of the user. When the user received them, the user had to run the robots through an exercise program and a simulated work program to find that certain gears did not have the proper design and certain components did not have the proper reliability to accomplish a consistent quality run. So... I'm asking each of our robot suppliers the following question: "How do you identify quality or the lack of it in a product or service?" And my best direction to those people is "Does the product consistently do the job it's supposed to do?" If the product—in this case, a robot—consistently—and the key is *consistently*—does the job it's supposed to do, it's reliable. Usually, robots are in a manufacturing process environment where if they break down, they could shut down the whole operation—Boom!—so they're very critical devices.

Getting back to Sterling Heights: When it launched it had only 102 robots. Now that plant is incorporating a second product to be launched next May—the P-Car, the Plymouth Shadow, and Dodge Sundance, and that plant will then have 222 robots. So we're dramatically committed to robots to assist us in our quality and productivity and flexibility aims in Chrysler Motors. But we need a much better performing robot as a key contributor to our new manufacturing philosophy.

> *We, as the customer, had not clearly articulated what our needs were to the robot manufacturers, and I don't believe that the robot manufacturers were articulating their needs to their suppliers or subsuppliers.*

Granted! A good percentage of our readers are either practicing engineers on the factory floor or their supervisors. They recognize that the performance of a robot is very much specific to the program. Robots are even left- and right-handed. Because of factors like hysteresis and backlash in the drivetrain, they may not perform precisely the same way in a right-hand motion as in a left-hand motion. Temperature can affect performance—certainly in terms of repeatability. Just the way a motion is programmed can affect robot performance. Also, since there is an infinite variety of programs a given robot can go through, a unique set of instructions may reveal a hidden defect—a defect the manufacturer just wasn't aware of. Exactly what is the program you're putting these robots through that is revealing these failures? Does the vendor get a very specific program to test it out before it's shipped to Chrysler? Or are they just getting general instructions?

A very good question. The important thing here is for the user or the customer—in this case, Chrysler—to clearly establish details as to what our requirements are for the environment in which that robot is going to work. Assume, simplistically, we need a robot to apply urethane to glass in a trim line like we would see at Windsor Assembly or Sterling Heights Assembly or the future Chrysler assembly plants. What is the temperature? The load? The cycling? The work envelope? All these different questions will be clearly enunciated to the manufacturer that we choose to produce the robot, and then any other clarifications that are required by that manufacturer will be answered by Chrysler. It is definitely not a general discussion: it's a very concise technical discussion, and every possible thing we can tell a manufacturer we do, to make his/her job more do-able—but then *we expect the results.*

It's interesting [that] in 1980 Chrysler had in its manufacturing processes robots produced by only one manufacturer—Unimation. Today, we have twelve different companies that made the robots in our manufacturing operations. We are constantly searching the world for the best robotic producers, whether they're in Europe, Asia, or North America. The technologies are changing, and we will continue to see who can best service our needs. [See Table 1.]

Would you please clarify the difference between the 50-hour test and the 20-hour test?

Basically, the 50-hour test is something like a breaking-in, a general review of the exercising of the robot, not necessarily at any one given speed or load or motion [and] not for any specific environment. It's somewhat generic. The 20-hour reliability test, however, is very specific to the application, and closely simulates the working load and conditions under which the robot will actually operate.

Bob Piccirilli and myself and others are actually spending days trying to communicate our needs to the various manufacturers and the trade association, because we represent a massive market segment and we simply do not want to have a "get better" mentality, we want an absolutely defect-free mentality. We're getting an outstanding understanding from the different chief executives and the chief operating officers of the 12 robot suppliers to Chrysler. They totally understand

there's a problem. They totally respect there's been a communications gap, and they want their industry to grow, their own company to grow, and they want to continue to be on the bid list for Chrysler.

The generation of robots we put into Windsor in 1983 were good robots, but they are not nearly as good as those we put into Sterling Heights in 1984, which, in turn, are not nearly as good as the ones we're putting into Dodge City, which will launch very quickly. The ones there will not meet the standards of what we want in the 1986 calendar year when we launch St. Louis, Missouri, where, by the way, we're going to go from 74 robots in the two assembly plants today to 320 robots by September. So, just a few months from now, St. Louis will have almost 400 percent more robots than it has today. While we've concentrated on the vehicle assembly division, we're now starting to massively multiply applications in our machining and casting operations in our powertrain division plants. We're also starting to use robots in a much, much greater way in our stamping and metalforming plants. [See Table 2.]

Table 1
Robot Population in Chrysler Motors by Manufacturer

Manufacturer	1980	1985
ASEA	0	38
Cincinnati Milacron	0	243
Devilbiss	0	4
General Electric	0	18
GMF	0	12
Graco Robotics	0	48
Kuka	0	14
Motoman	0	7
Prab	0	88
Robotics Inc	0	16
Unimation	197	386
Other	0	26
TOTAL	197	900

Table 2
Robot Population Within Chrysler Motors — by Application
1985

	Assembly Plants	Stamping Plants	Powertrain Plants	Other	Total
Spot Welding	670	—	—	—	670
Material Handling	6	39	14	—	59
Spray Painting	56	—	—	—	56
Training & Misc. Other	9	—	—	21	30
Adhesive/Sealant Application	12	15	—	—	27
SubAssemblies	26	—	—	—	26
Assembly	—	—	15	—	15
Arc Welding	6	1	—	—	7
Glass Preparation	5	—	—	—	5
Machine Loading	—	4	1	—	5
TOTALS =	790	59	30	21	900
Electric Drive =	404	41	26	N/A	
Hydraulic Drive =	386	18	4	N/A	

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

1	11	21
Excellent	Good	Fair

Continued from page 6

- quality measurements
- error cause removal
- repeating the process—QIP is a never-ending process demanding constant assessment and adjustment.

Chrysler's long-range plan calls for spending $12.5 billion in the next five years. Manufacturing is expected to get 41 percent or $5 billion plus. Out of this $5 billion, suppliers of facilities, tooling, and equipment can expect to get $4 billion. Robot builders are expected to get a significant portion of that $5 billion.

In addition to introducing seven new models over the next 36 months, Chrysler has three specific goals for the next five years:

- Defective quality citations/100 vehicles must decrease by 56 percent.
- Costs must decrease by 30 percent, or over $2000/vehicle.
- The time to bring a new vehicle to market has to be cut 25 percent—from five years to less than four years.

Chrysler's expansion plans call for investing close to $0.5 billion in the Dodge City complex in Warren, Michigan which will produce large or small pickups in any ratio between 0 percent and 100 percent. At startup, March, 1985 156 robots and 835 computers were installed—representing a buildup from only one robot and 53 computers in only 12 weeks. Clearly, unproven or unreliable systems at any startup spell disaster. Future plans call for 2350 robots in Chrysler by 1990—a 161 percent increase over 5 years. [See Table 1.]

A "bare bones" robot costs about $90,000. On average, the total investment, including plant facilities, tooling, and installation, is generally some two-to-three times that of the robot itself, or about $300,000. The 1450 robots we plan to install over the next five years will cost approximately $500 million. The $5 billion manufacturing capital investment must create a vehicle that is cost-competitive and that takes less time from the drawing board to the dealer showroom. Unless quality is built into these manufacturing systems, quality goals and production plans simply cannot be implemented. We've taken steps to ensure that equip-

Table 1
Anticipated 161 Percent Growth in Robot Population at Chrysler

Year	1985	1986	1987	1988	1989	1990
Robots	900	1140	1440	1960	2190	2350

The investment is expected to total $500 million.

ment and systems are consistently reliable—as received by our plants. All robots received by any plant or systems integrator on our behalf must pass a 50-hour quality test wherein the equipment is exercised through its design parameters for 50 hours. An actual tool or simulated load is attached to the wrist and the arm is exercised through all axes of motion.

Results of the 50-hour test shocked us. Of the 200 or so robots tested under the program, about 50 broke down before we even attempted the application. No robot, American, Japanese, or European passed. The top five problems were:

- Drive motor circuit board failures—the boards had to be redesigned.
- Defective drive mechanisms had to be replaced.
- Incorrect fuses had to be replaced.
- Software problems. On powerup, the robot would occasionally move unexpectedly. The software had to be debugged.
- Overloaded drive mechanisms. Arms had to be stiffened and weld guns redesigned.

Had these systems and robots entered the assembly plants without the 50-hour test, quality and production would have been badly hurt, and launch programs could not have been met on time.

In addition to our 50-hour test program, all equipment has to pass a 20-hour reliability test before we allow it to be shipped to our plants. In this test (at the equipment build source), the robot must cycle automatically—without any break whatsoever—for 20 continuous hours. The 20 hours approximates a full day's actual service. Any breakdown or failure requires the clock to be reset to "time zero" and the test restarted—until a successful run has been completed. All process equipment, not just robots, must pass this test. A key purpose is to establish equipment reliability independently from product quality in an actual production environment.

Again, the results of our 20-hour reliability test program have dramatically proven our need to place quality and reliability at a higher level in our plans. For systems intended for just two assembly plants, we experienced 393 breakdowns on 48 systems—causing up to 10 days' quality nonconformance just to secure a 20-hour continuous run. The true impact is that it kept 393 *major breakdowns* out of our Dodge City and Sterling Heights Assembly plants—avoiding the loss of as much as $10 million per day per plant!

Finally, a look at the future. In our three most modern assembly plants, there are only two or three robots in what we call the "Trim, Chassis, and Final" (TC&F) areas. We believe this is where robotic growth opportunities lie, and we're now firming up plans for a cooperative process development program whereby the TC&F areas can be at least 80 percent automated. The robots will have vision and intelligence plus self-diagnosis and recovery. Future technology in Chrysler plants will depend on what we can accomplish in this development program.

Results of the 50-hour test shocked us. Of the 200 or so robots tested under the program, about 50 broke down before we even attempted the application. No robot, American, Japanese, or European passed.

justification for the next overseas move ... tion. While labor costs are on the increase ...

Justifying High-Tech Manufacturing Solutions Through JIT-TQC-CIM

Dr. Ani D. Chitaley
Automation Management Services, Inc.
3580 Mark Drive
Broadview Heights, OH 44147

Manufacturers worldwide are fighting to increase productivity and win in the international marketplace. Over the last 10 to 15 years, several Japanese and Korean manufacturers have established themselves in industries traditionally dominated by U.S. manufacturers. The U.S. has lost leadership in industries that manufacture products such as ships, clothing, cameras, cars, video and audio recorders, televisions, and high-volume semiconductors. Other fields such as computers, telecommunications, satellites, software, chemicals, and aerospace are not yet lost.

Experts from several large accounting and management consulting firms suggest that future manufacturing will be led by Japan and other Asian countries and that the U.S. economy will be led by the service industry. But others who understand manufacturing economics believe that this could only be a self-fulfilling prophecy. The pressures for short-term returns on investment or the acceptance of a distributorship sort of business strategy has pushed several U.S. firms to either give up manufacturing some product lines or move overseas in the hope of benefiting from lower labor costs and subsidies. The effect of this strategy, however, is becoming more and more clear. A portion of every manufacturing dollar spent outside the firm nurtures the vendor, creates his manufacturing assets and supports his fixed costs. This vendor could be your future competitor. In many high-tech businesses, loss of manufacturing strength could also mean eventual loss of R&D product technology leadership.

Can U.S. high-tech businesses remain viable as leading developers and product inventors, reaping high-margin benefits in the first few years of new product cycles and then leaving manufacturing to international competition? The answer seems to be a definite "No," as many firms dealing with semiconductors, computers, and other products are coming to realize. Many U.S. manufacturers are fighting back and winning. How to successfully apply manufacturing know-how in high-tech businesses to obtain long-term leverage is our subject.

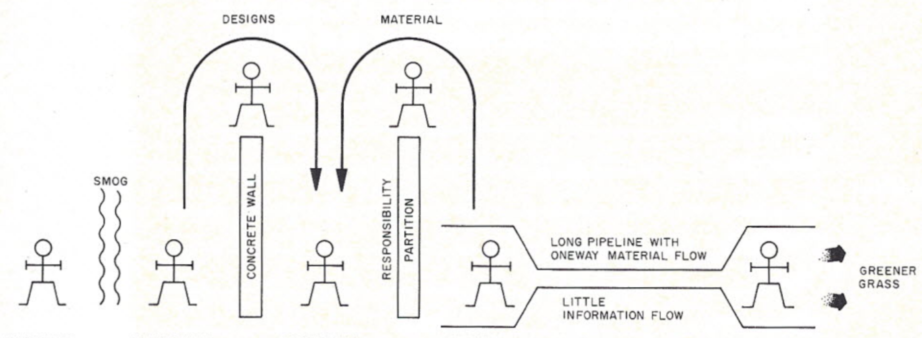


Figure 1. The working relationship between design and production engineers can be represented as a volleyball game over a concrete wall.

AUTOMATE, EMIGRATE, OR EVAPORATE—THE CATCH 22

This manufacturing philosophy reached North America a few years ago, and it seemed that at every social function some executive would declare his firm's automation or emigration strategy. Still, many high-tech firms have found it difficult to implement this philosophy. Some even realized the pitfalls. Four major factors worked against their survival intentions: the nature of the high-tech product-process cycles; the use of conventional, labor-based accounting; the socioeconomic differences between the U.S. and the Far East industries; and, the automation of shop floor activities such as fabrication and assembly, which could not in itself vitalize the manufacturing arm of the company. Let us take a closer look at these factors.

The High-Tech Product-Process Cycle. The nature of transitioning R&D product technology through initial prototype, pilot,

and on to full-scale manufacturing is such that the effectiveness of the manufacturing system and the ability to introduce mature designs are closely interdependent. We will use the term "manufacturing" to include all system functions such as product design, process design, production, purchasing, cost accounting, and other decision support elements.

The characteristics of the cycle are

- High rate of design changes
- New processes
- Technological uncertainties
- Short product life cycles, and short time frames for designing, scale-up, manufacturing, and phase-out
- High-risk decisions

In the initial stages, the R&D function has cost and time pressures for product introduction, while production most often resigns its fate to living in the imperfect world of Engineering Change Notices. In many cases, it is analogous to a volleyball game over a concrete wall (Figure 1). In other words, manufacturing and design functions require such close interfacing in the initial stages that the project is difficult to pull off successfully if initial production is a vendor's responsibility. Further, if production is moved overseas under these circumstances, the chargeback for engineering changes and initial field problems falls into the production bucket as overhead, like most common accounting practices.

Conventional Accounting Practices. The movement of production to overseas vendors also means a decrease in capacity use and excess of overhead in the U.S. plant. While top management reacts favorably to the immediate cost-reduction benefits from moving overseas, plant closing and reduction of overhead are many times left within the scope of production operations. The end result is an increase in "burden rate" for every overseas move, thereby creating justification for the next overseas move, leading eventually to a loss of manufacturing strength.

Furthermore, as the direct labor percentage reduces, the overhead burden rate based on direct labor becomes artificially higher. It is unfortunate that while our accounting professionals are busy implementing accepted accounting principles for external business financial reporting, little attention is paid to the need for accurate cost accounting as a decision support tool.

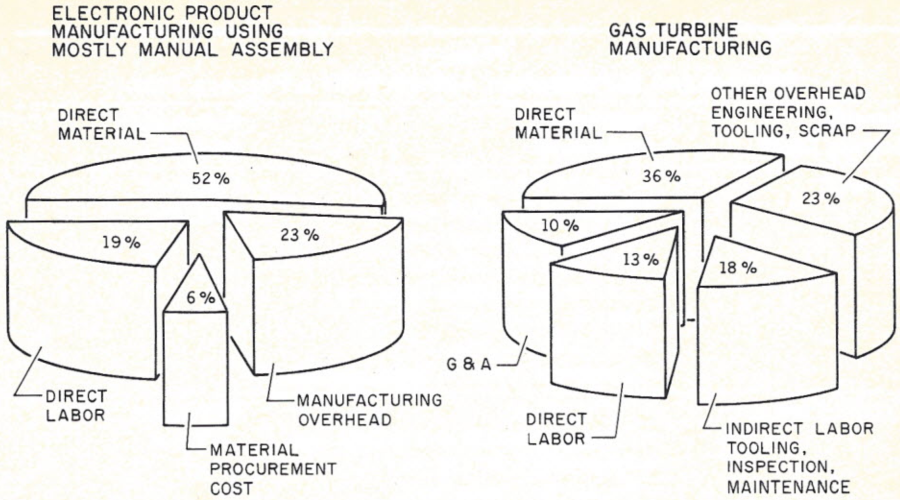


Figure 2. A breakdown of typical manufacturing cost elements demonstrates that direct labor is only a small factor—as little as 3 percent in some instances.

The Power of the Socio-Economic Weapon. Except for theoretically vertically integrated businesses, most manufacturers depend on a significant portion of incoming raw materials to consist of value-added subcomponents ready for assembly. Some even benefit from the high-margin systems integration activities. But the supplier–buyer relationship's viability is based on the premise that the vendor is not a potential competitor. U.S. businesses, accustomed to the economic freedom and business practices within the continent, find it difficult to foresee or to accept the moves of their international collegues. For example, even a cursory look at the management structure of 10 major Japanese companies and the 3 major Japanese national banks reveals the financial integration of the industries. Add to this the lifelong relationship between a Japanese company and its management and other workers, and the patience of the investors.

Comparing business strategies on a one-to-one basis is meaningless in this situation. While labor costs are on the increase in Japan (although the rate of productivity increase still exceeds that of the U.S.), other low-labor-cost nations such as Korea and China are bound to move into manufacturing. Thus, U.S. manufacturers can always find vendors willing to outbid any quote by their in-house operations, as long as the volumes are large enough. The eventual loss of manufacturing capabilities and proprietary product technology is the only trade-off against short-term economic pressures.

An added complexity in recent times has been the practice of differentiated raw materials pricing by many overseas suppliers. People with experience in operating U.S. Asian plants are aware of 30 to 40 percent average cost differences between semiconductors, other electronic components, wire harnesses, moldings, and so forth supplied to the local plants vs. those supplied to the U.S. plants on shore.

Shotgun Automation. The early 1980s rush toward robotics and flexible manufacturing systems (FMSs) as a cure for manufacturing ills is now settling down to more appropriate levels. In those years, automation of shop floor tasks such as fabrication, assembly, inspection, and material handling was seen as a solution for reducing or virtually eliminating shop floor labor. Many automated storage and retrieval systems erected in those days are now coming down. The shotgunning of shop floor labor through automation did not always produce the desired improvements in manufacturing productivity. The reason is simple enough. Figure 2 shows typical manufacturing cost elements in two high-tech industries. Direct labor is only a small fraction of the total cost. In some computer manufacturing operations, direct labor can be as much as 3 percent of total cost, while materials are almost 70 percent. With the improved technologies and increased operations management complexities of the last two decades, overhead costs as a percentage of value addition have steadily increased, while direct labor percentages have declined.

Table 1
Support and Management Activities for a Process Task

Manual Activity Level	Functions Performed	Automation Device
Operator	• Equipment Setup • Operation Stop/Start and Processing Controls • Part Test/Inspect/Record • Job/Operation Status Reporting • Material Movement • Equipment Maintenance • Equipment Condition Status Reporting	Equipment Controller
Operator/Foreman	• Lot Stop/Start • Process Balancing and Material Flow • Processing Specifications Storage and Assignment • Part Test/Inspect/Record • Job Status Reporting • Material Movement	Workstation Controller
Foreman/Supervisor	• Factory Data Consolidation/ Preprocessing • Cell Job Dispatch • Process Balancing and Material Flow Control • Processing Specifications Pass-through • Cell Communications Handling	Cell Controller
Plant Manager	• Detailed, Short-interval Work Order Scheduling • Plantwide Job Dispatch • WIP Tracking and Management • Factory Data Collection and Reporting • Processing Specifications Pass-through • Test Specifications Pass-through	Production Control Distributed Processor

Recent studies by the American Electronics Association suggest that in the electronics industry simple manufacturing systems such as job shops for government projects have overheads of approximately 60 percent of value added, and the ratio increases to almost 70 percent for the microcomputer industry, where high volumes and automated processes lead to increasingly complex manufacturing operations.

The focus of direct-labor-cost reductions through process-equipment-based automation (mechanization) generally also requires a greater initial investment per dollar saved than the application of systemization solutions. Also missed have been the significant opportunities for material cost reduction through appropriate product design solutions and purchasing techniques. A case in point is the use of standard equivalent chip packages by offshore vendors replacing "hard-to-procure" components specified in a U.S. logic board design. The cost savings opportunities through a reduction of indirect activities can be seen in Table 1, which illustrates the support and management activities typically performed for a single-shop floor process task.

JIT-TQC-CIM: A UNIFIED APPROACH FOR MANUFACTURING SOLUTIONS

Global competition has seriously challenged our understanding and implementation of production, operations, process technology, inventory control, and quality control. World-class manufacturers are being forced to perfect production, process, and quality control techniques in the search for higher quality, timely delivery, and lower product cost. Just in time (JIT) and total quality control (TQC) are two powerful tools for achieving these objectives. Another is computer integrated manufacturing (CIM). JIT-TQC can prepare the ground and provide an approach for implementing viable automation solutions.

JIT-TQC Can Lead The Way. JIT has received a number of labels since it was discovered in the U.S., applied successfully by the Japanese, and rediscovered by U.S. manufacturers. It has been called a pull-type scheduling system (*Kanban* in Japanese), an inventory reduction program, a setup time reduction program, the road to automation, and so on.

The accompanying representations do not define JIT but only list some of its features. JIT is a philosophy and a technique of continually reducing waste in all aspects of manufacturing (Chart 1).

The practice improves the health of the manufacturing operations. It affects design, plant layout, processes, quality management, purchasing, vendors, employee relations, and financial operations. It reduces finished goods, incoming and work-in-process inventory, and leads to small batches, quick setups, and reduced throughput time.

TQC is necessary for implementing JIT and is an integral part of the JIT philosophy. A major pitfall for firms implementing JIT is a lack of sufficient focus on TQC. Quality and process problems are exposed by JIT techniques, while TQC solves them. Reducing incoming inventory requires integration with vendors' process quality and delivery schedules. Reduced work in process, small batches, quick setups, and reduced throughput time all require preventive quality measures and "no surprises" during operations. This is possible only with high equipment uptime, process control, material quality, and a smooth transition of design-to-production.

Results for companies successful in implementing JIT-TQC are impressive. A U.S. computer manufacturer recently saw these benefits:

- 50 percent reduction in manufacturing floor space
- 85 percent reduction in product manufacturing throughput time
- 90 percent reduction in machine setup time
- 80 percent reduction in work-in-process materials
- 200 percent improvement in process quality
- 83 percent reduction in scrap and rework

Generally, the Engineering Change Notices that flow between engineering and production are an indirect reverse measure

Chart 1
The Interlinking Impacts of JIT-TQC Implementation

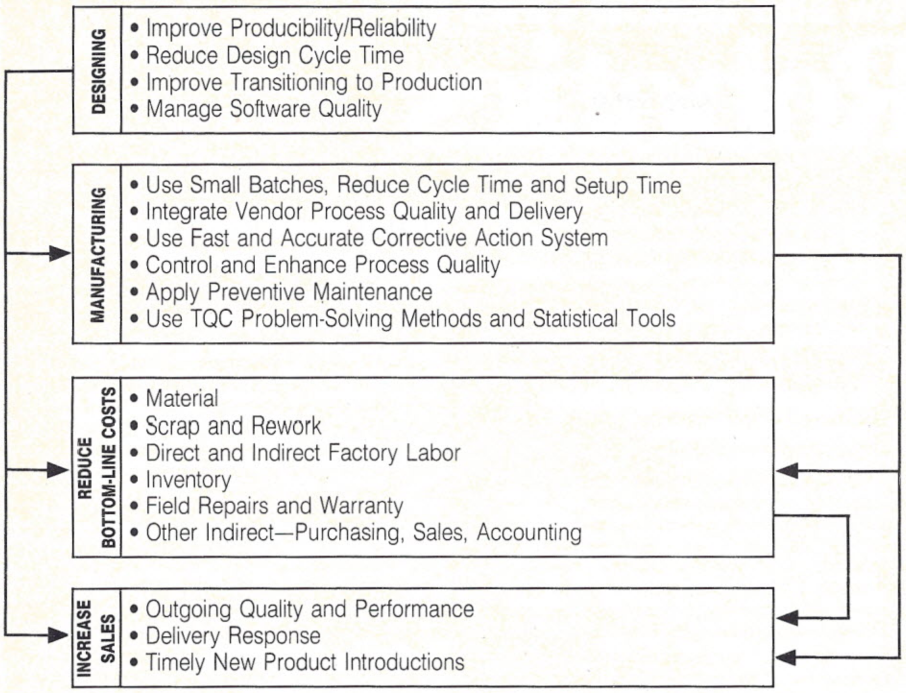
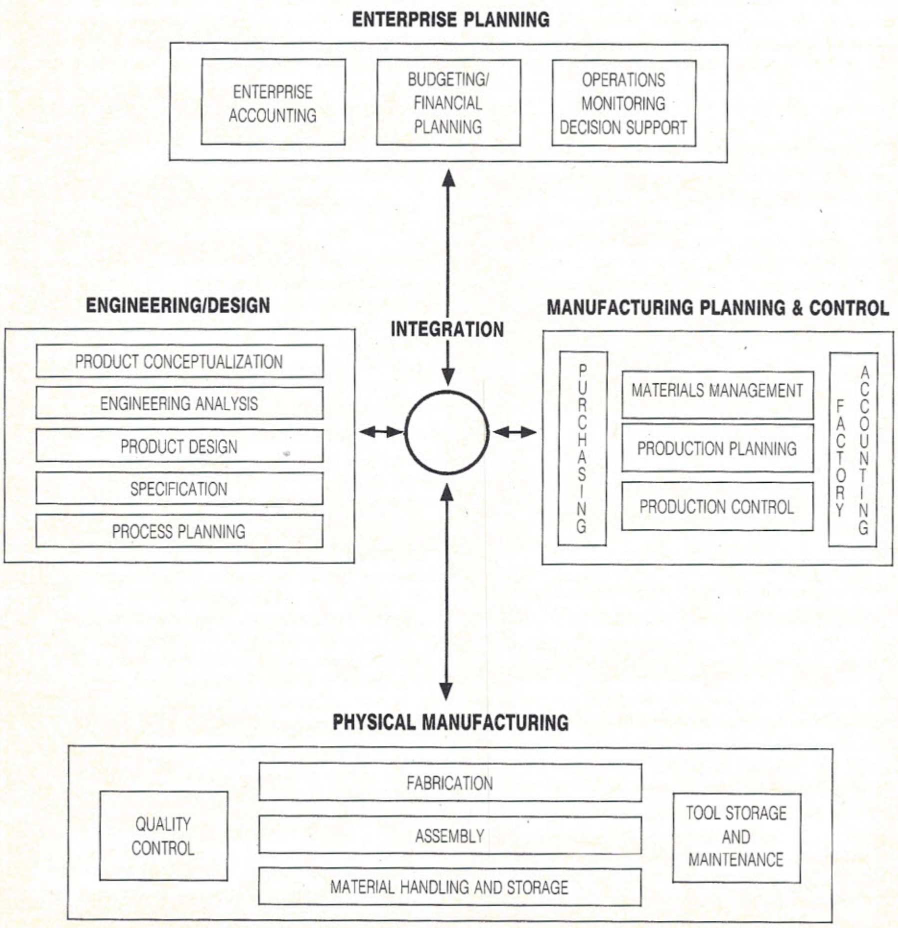


Chart 2
Functional Areas Covered by CIM



of the maturity of the design as it is released for production. In some high-tech businesses, ECNs continue at a high rate almost throughout the design life. The costs of changes, defectives, and scrap remain hidden in the production budget, while management finds it difficult to identify the root cause of high production costs and schedule overruns. JIT-TQC also provides long-term benefits in this situation. The improved designs reduce material, assembly, test, and inspection costs. Improved management of the design-to-production transition reduces total project time and cost. Chart 1 illustrates the interlinking effects of JIT-TQC implementation.

JIT and TQC are not complex concepts, nor do they involve complex techniques, but implementing them is difficult because new ways of thinking are involved. With experienced help, successful JIT-TQC pilot projects can be started in 30–90 days, although it may take several months, or years, before JIT-TQC becomes a modus operandi. Are the results worthwhile? For an increasing number of companies, learning about and implementing these breakthrough manufacturing methods is quickly becoming a matter of survival.

IMPLEMENTING CIM IN HIGH-TECH COMPANIES

Computer integrated manufacturing involves computer aided functions in all activity areas within a manufacturing system (not just the factory) and the integration of functions (where necessary) through electronic communications and data sharing. CAM (computer aided manufacturing), robotics, and robotic controls are subsets of CIM on the shop floor. CAD and CAPP (computer aided process planning) are subsets as applied to engineering/design activities. Chart 2 shows the functional areas covered by CIM.

Computers increase the flexibility, speed, reliability, and repeatability of tasks and allow their integration with other related tasks. This capability is used to perform both shop floor and other indirect activities. Except in the case of a totally automated system, CIM involves a mixed deployment of human, machine, and computer capabilities. Dedicated automation systems such as those for conventional assembly lines are appropriate for high product volumes, product designs with in-

frequent changes, and a market with delivery and price pressures. Flexible manufacturing systems that involve significant shop floor automation of fabrication, assembly, and material handling, on the other hand, are appropriate when product designs must change frequently. These systems are applicable to relatively higher volume, more stable stages of some high-tech businesses.

Major benefits come from indirect activity areas such as factory overhead and R&D. But FMSs have two major limitations: tooling and hardware remain relatively inflexible, and fixed costs increase significantly, thereby increasing risk in changing markets. For high-tech businesses that deal with relatively lower volumes and that leverage frequently improved designs/technologies, a flexible human system approach could be more appropriate.

Flexible human systems can lead to more cost-effective manufacturing solutions because of their attack on all indirect and support activities and information flows beyond the direct labor tasks. They automate shop floor tasks only to an extent that will reduce or eliminate subsequent support tasks such as those for planning, scheduling, and quality control.

JIT-TQC As First Steps Toward CIM. One of the major pitfalls in implementing CIM is the automation of functions without changing the conventional methods of operation. Such direct automation efforts result in automated wire-guided material handling systems, high-rise storage areas, and complex inventory planning and control systems. None of these would be necessary if inventory were minimized and a JIT pull system established. While the ultimate JIT, *Kanban* ticketing, may not be applicable in all manufacturing situations, the simplification of functions and elimination of unnecessary tasks before automating them is the key. JIT-TQC allows us to achieve the inherent limit of current process capability by improving all operations and productivity. Automation with continuing JIT-TQC then improves the limit of process capability and productivity.

In high-tech industries, design and manufacturing engineering are key functions that affect manufacturing cost, quality, and delivery. The producibility, testability, and reliability of the design can dictate material cost, direct assembly, and test labor, all indirect labor such as scheduling, planning, supervision, quality assurance, scrap and rework, process equipment, fixturing expenditures, and even plant floor space. Improving designs through the application of "design for assembly" rules, producibility guidelines, and improving the design-to-production transition can offer significant savings in material, burden, and direct labor and can improve quality as well. Computer aided design and process planning allows us to effectively implement the JIT-TQC approach. This is a powerful approach for CIM, which is the technological tool for future manufacturing systems solutions.

Dr. Chitaley is President of Automation Management Services, Inc.

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Excellent	Good	Fair

Multiple-Arm Control and Assembly Operation

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Robots and vision technology have advanced to a point where the ideal of flexible assembly is a reality. A demonstration flexible assembly cell designed to assemble automotive oil pumps has been built to incorporate the following capabilities:

- Sensory-driven assembly
- Dual robot communication and coordination of overlapping work envelopes
- Real-time process verification
- Real-time response to errors
- Real-time assignment of task priority
- Cell control integrated into multitasking robot controller (no separate cell controller)
- Simple parts feeding (no "tooled" parts presentation)
- Complete assembly within one cell (the opposite of sequential assembly lines)

In this article, we will look at the oil pump and the assembly layout, part presentation, the sensors employed, assembly sequence, and, finally, cell control and programming, highlighting how priorities were determined in real time to guide the robots to the proper assembly sequence.

THE OIL PUMP

The oil pump (Photo 1) consists of eight parts:

1. Housing (1) 2. Mating gear (1) 3. Shafted gear (1) 4. Cover (1) 5. Bolts (4)

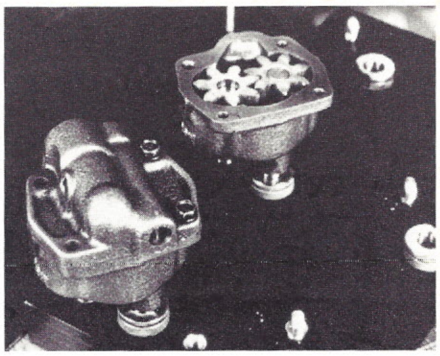


Photo 1. The oil pump to be assembled consists of eight parts.

An assembly begins with the housing. The mating gear is inserted over a shaft in the housing, followed by the insertion of the shafted gear. The cover is then placed on top and secured with the four bolts.

THE CELL LAYOUT

Based on the initial cycle time analysis, the cell was designed with three assembly stations accessible to both robots. The entire system (Photo 2 and Figure 1) consists of:

1. Two AdeptOne™ robots and controllers; a five-axis AdeptOne was the transfer robot and a four-axis AdeptOne was the assembly robot
2. Moving-line AdeptVision™
3. Arm-mounted area AdeptVision
4. Z-axis force sensing
5. Arm-mounted screwdriver
6. Instrumented grippers
7. Three instrumented assembly stations
8. Gear presentation tray
9. Bolt presentation tray
10. Simple 12-in. wide belt conveyor
11. Finished parts pallet

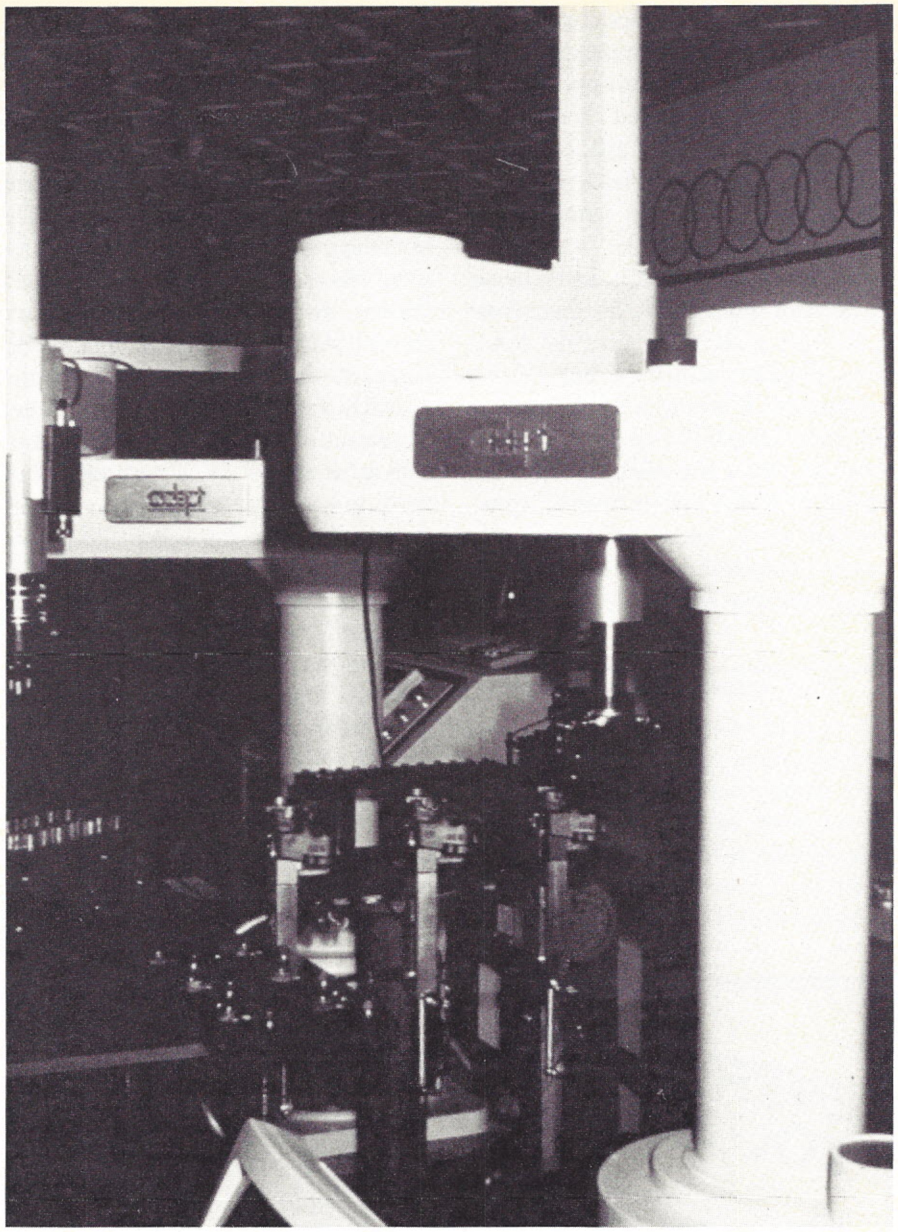
PART PRESENTATION

The parts feeders where designed to demonstrate two capabilities. First, the feeders are "simple" in that they are not tooled for a specific part. Therefore, the same feeders can present different parts and the cell can be truly flexible, capable of assembling a variety of pump products. Second, the feeders present housings, covers, and gears in random orientations and positions to demonstrate that it is no longer necessary to precisely position parts in order for the robot to find them.

The belt conveyor feeds pump housings and covers to the transfer robot. The housings and covers travel on the belt at random intervals and in random positions and orientations. The moving-line vision system locates the parts by constantly monitoring the conveyor and identifying their location on the belt, and communicates part locations to the transfer robot.

The shaft gears and mating gears are

Photo 2. The workcell consists of two robots with overlapping work envelopes, vision and other sensors, a simple conveyor belt, and the robot controllers.



loosely presented on a simple tray in the assembly robot work envelope. Area vision locates their exact positions and identifies grip points. The tray of gears is too large to be viewed with a stationary camera, so the camera is mounted on the robot arm where the robot can control camera position as needed. The bolts are also presented on a simple tray within the work envelope. The position of the bolts is known accurately enough that no vision capability is needed to locate them.

SENSORS

Several tasks require sensory interaction in order to reliably perform the assembly. Some of the most important sensory tasks include detecting part acquisition and placement errors and recovering appropriately, inserting gears reliably, and automatically fastening the four bolts.

Real-time errors must always be anticipated when acquiring and placing parts. In this cell, errors can occur when taking parts from the belt, gear tray, or bolt tray. Placement errors can include improper placement onto the assembly station, improper setup of the station, and improper driving of the bolts.

To detect errors when acquiring housings and covers, simple contact switches in the transfer robot gripper indicate whether the part is in the gripper. Contact switches in the assembly stations detect that the housings are placed correctly. A pneumatic cylinder in each assembly station actuates a locating pin on which the housing is seated. If this pin does not extend or retract at the appropriate times, the assembly can fail. Therefore, magnetic presence sensors in the assembly station verify that the pin is in its proper position.

To reliably insert the gears, a Z-axis force sensor on the third axis of the assembly robot detects jamming and guides the robot to apply corrective moves. For example, when placing the second gear into the housing, the robot spins the gear about its vertical axis until the force sen-

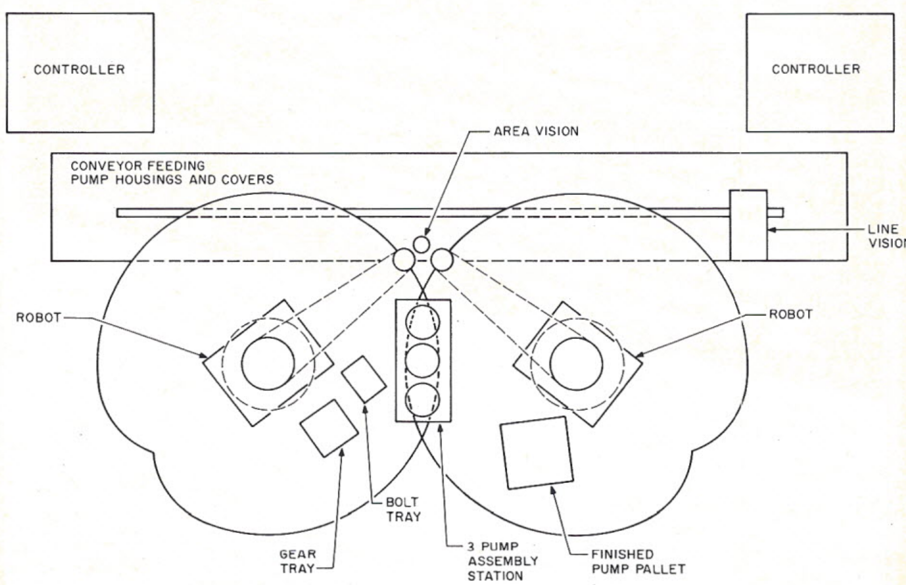


Figure 1. The two robots constatly exchange status reports and use state tables to prioritize tasks.

sor detects the gear is meshing with the first gear. Then the robot releases the second gear and drops it into place.

A computer-controlled screwdriver mounted inside the third axis, or "quill," of the assembly robot automatically fastens the four bolts. A torque sensor in the screwdriver monitors the screwdriver torque to assure the bolt is driven home. To detect a jammed bolt, another sensor in the spring-loaded head of the screwdriver detects whether the bolt head is compressed. If torque is sensed without the bolt's being fully inserted, a jam has occurred. Other possible problems when driving the bolts—such as missing screws, dropped screws, misaligned holes, or a jammed screwdriver—are also detected using these two sensors.

CELL COMMUNICATIONS

Most of the communication channels are straightforward. Since only the transfer robot requires information from the line vision systems, the vision processor resides in the transfer robot's controller and communicates to the transfer robot via the controller backplane. Similarly, the arm-mounted area vision processor resides in the assembly robot's controller. All AdeptVision systems are integrated into the Adept controller, so no additional mechanical or software interface is required.

The two sensors in the screwdriver are wired directly to the binary I/O ports of the assembly robot. Since only the transfer robot places housings onto the assembly stations, the magnetic presence switches for each station are wired into that robot. However, the contact switches on the assembly stations that indicate the correct placement of housings are connected to both robot controllers. The transfer robot needs to know that a housing is correctly placed before releasing its grip. Since there is a chance that a housing can accidentally stick and become unseated during gear placement, the contact switches also need to go to the assembly robot controller.

Finally, the two robots communicate status information to one another via an RS-232 serial communications channel. For example, the transfer robot can indicate to the assembly robot that a housing in Station #1 is ready for gear insertion. In addition, location information is traded to avoid collisions. The assembly robot is notified to stay out of a particular station when the transfer robot is there.

THE ASSEMBLY PROCESS

The assembly sequence begins when the moving-line vision system recognizes a pump housing on the conveyor belt. The transfer robot frequently polls the vision system. When the housing is recognized and an assembly station is available, the robot tracks the conveyor and acquires the housing with an electromagnetic end effector. Immediately after the electromagnet actuates, the contact switches in the gripper are checked to ensure that the housing is securely gripped. If the housing is present, the transfer robot places it in the open assembly station. If a housing is not sensed, the robot retracts to wait for another housing or performs another of its tasks.

During the transfer robot's move to the assembly station, it signals the holding pin in the assembly station to extend. When the magnetic presence switch indicates that the pin is extended, the robot places the housing on the station, checking the station contact switch before releasing the

part. If the contact switch indicates that the housing is not seated, a routine is executed to move the housing in small increments until properly seated. The transfer robot then leaves the station and signals the assembly robot that a housing is in place and waiting for gear insertion.

The assembly robot requests that a picture of the gear tray be taken whenever the robot arm is near the tray. The recognized gear information is fed into a software queue that is accessed by the assembly robot when it needs to acquire a gear. When the transfer robot signals that the housing is in place, the assembly robot acquires a mating gear and moves to the assembly station. Then a command

Integrated vision, integrated control, and extensive sensory communications actually simplify an assembly cell rather than complicate it.

is executed to move in a vertical direction while sensing for force overload. If an overload occurs, the robot turns the part about its axis to relieve the jam. Upon successful insertion, the robot returns to the tray and acquires a shafted gear.

The shafted gear is placed in a similar manner but with two additional steps. The holding pin must be retracted when the shafted gear is placed, so the robot checks a magnetic presence switch to ensure that the holding pin is retracted. Also, as the robot moves in the vertical direction to place the gear, the force sensor is monitored to determine when the two gears have meshed.

After both gears are successfully placed, the assembly robot signals the transfer robot. The transfer robot has already polled the line vision system to locate a cover. It then places the cover on top of the housing assembly and "holds" the cover in place while the assembly robot is signaled to insert the first bolt. After the first bolt is inserted, the transfer robot leaves the station because the cover is now secured for the three remaining bolts.

When the gear insertion is complete and

Continued on page 24

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while the transfer robot is placing the pump cover, the assembly robot goes to the bolt rack and acquires the first bolt. The compression sensor is checked before removing the bolt from the rack to ensure that the head has fully seated. If it has not, the sensor directs the robot into a search routine. The screwdriver is turned on in reverse for a preset time to remove the bolt. The compression sensor is checked again to ensure that the bolt is present in the screwdriver head. If the bolt is missing, the robot returns to acquire another bolt. Once the bolt is securely in the screwdriver and the transfer robot has sent the go-ahead signal, the assembly robot inserts the bolt, using the two available sensors.

When the transfer robot has left the assembly station, the assembly robot goes on to insert the other three bolts and complete the pump. The transfer robot is signaled to remove the pump from the assembly station and place it in a pallet of finished pumps.

This application sequence results in an average assembly time of 40 seconds per pump. Several changes to the cell design could improve this throughput rate. First, the bolts could be automatically fed into the screwdriver rather than acquired from a rack. Also, multiple screwdrivers could be used. Second, a simple pneumatic actuator could hold the cover in place so the transfer robot would be free to do other tasks. Third, with these changes the transfer robot would spend much of its time waiting for the assembly robot, so the cell should be designed so that one transfer robot feeds two assembly robots. With these changes, the assembly time might be reduced to 15 seconds per pump.

Table 1

Assembly Robot Controller		Transfer Robot Controller
Cell Control • Robot-to-Robot Communications	← → RS-232 Serial Communications	**Cell Control** • Robot-to-Robot Communications
Robot Control • State Table Polling • Executing Highest Priority Task Subroutine • State Table Updating		**Robot Control** • State Table Polling • Executing Highest Priority Task Subroutine • State Table Updating
Vision Control • Recognize and Locate Gears in Tray		**Vision Control** • Recognize and Locate Pump Housings and Covers on Moving Conveyor

CELL PROGRAMMING AND CONTROL

Since there are three assembly stations and the mix of tasks waiting to be accomplished changes from moment to moment, task priorities are assigned based on the "state" of each assembly station. Each robot has a set of state tables that define the order of operation, the relative priority of each task, and the current status of the pumps in each of the three assembly stations. The state tables are continuously scanned and the highest priority task is

executed. Each specific task—such as the task of placing a housing onto an assembly station for example—is written as a subroutine that the robot calls up and executes when the task reaches the highest priority. Because of state table programming, the assembly tasks described earlier are never followed without interruption at any one assembly station. The actual order of tasks is determined in real time, based on the highest priority task at all three stations.

To illustrate the effect of state table programming, we will compare two different situations. Let's assume two assembly stations have pumps and the third station is empty. The transfer robot polls the moving-line vision system and learns that another pump housing is available. In one situation, the assembly robot is inserting gears and does not require the transfer robot. Getting another pump for the third assembly station becomes the highest current priority and the transfer robot acquires the pump. In the second situation, the assembly robot has already inserted the gears and is waiting on the transfer robot to place a cover. Getting a cover is a higher priority task than getting a housing because the assembly robot will be idled if the transfer robot takes time to get another housing. So the housing is ignored on the belt and the transfer robot gets a cover instead.

Table 1 illustrates the functions of the cell control program and the functions of each robot's program. As shown, the cell control function does not require a separate programmable controller. The Adept robot controller can simultaneously and asynchronously run two separate programs and can therefore act as both the robot controller and the cell controller. For this cell, it was not necessary to designate a control robot versus a slave robot. Instead, both robots run a cell control program that continuously updates the state tables.

Both the cell control programs and the robot control program are coded in VAL-II™, Adept's programming language. (VAL-II is a trademark licensed to Adept Technology, Inc). The vision systems described earlier are also integrated into the controller and programmed in VAL-II.

SUMMARY

The complete assembly of an automotive oil pump in one two-robot cell illustrates state-of-the-art vision-guided robotic assembly. Most important, it illustrates that integrated vision, integrated control, and extensive sensory communications actually simplify an assembly cell rather than complicate it. Because of robot guidance vision, part presentation is simplified and more flexible. Since the vision is integrated in the robot controller, the addition of vision does not complicate the overall cell design.

With built-in communications capacity, the sensors needed to verify the process and respond to errors are easily added to the cell. Because of integrated cell control, real-time task assignment is possible without adding a cell controller, and the two robots' motions are smoothly coordinated within overlapping work envelopes.

Gordon Mayer is Technical Marketing Director and **Elaine Ide Wood** is Market Development Manager for Adept Technology, Inc.

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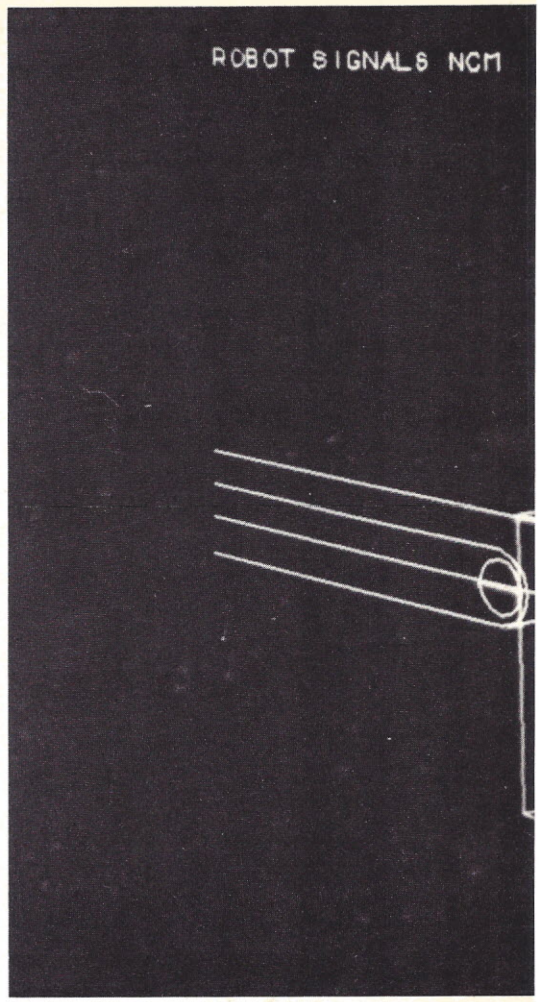
The Simulation and Programming of Multiple-Arm Robot Systems



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Los Altos, CA 94022

Today's automated factories often employ robots, vision systems, tactile sensors, and programmable controllers. Many times there are multiple robots involved, but in separate workcells. It is rare to see two or more robots truly cooperating, with overlapping workspaces and interspersed actions, despite the fact that close cooperation between robots can greatly increase the efficiency and flexibility of workcells.

Fixturing can often be shared, and idle time for robots and other equipment minimized by effective scheduling. Some complex assembly operations cannot be automated at all without the use of multiple cooperating robot arms. The main obstacle to the implementation of this form of robotic automation is the complexity of the planning and the programming required. It is here that computer-based robot simulation systems have much to contribute.

THE ROLE OF COMPUTER SIMULATION

Simulation systems allow the user to experiment with various workcell layouts, simulate the kinematic and dynamic behavior of specific robots, and generate programs for them off line. Unfortunately, most simulations are unable to handle more than one robot at a time, rendering them unusable for planning and programming the automation systems that most need their help: multiple-arm robot systems. To address this need, Silma, Inc. has developed the CimStation™(Photo 1) to which a multiple-arm simulator has recently been added.

CimStation is used to create and modify a computer-based three-dimensional model of one or more robotic workcells, for writing robot programs, and for creating computer graphic animations of particular robots executing their programs. The user observes whether robots can reach their goal points and whether any collisions will occur, and receives cycle time estimates. The operator can then

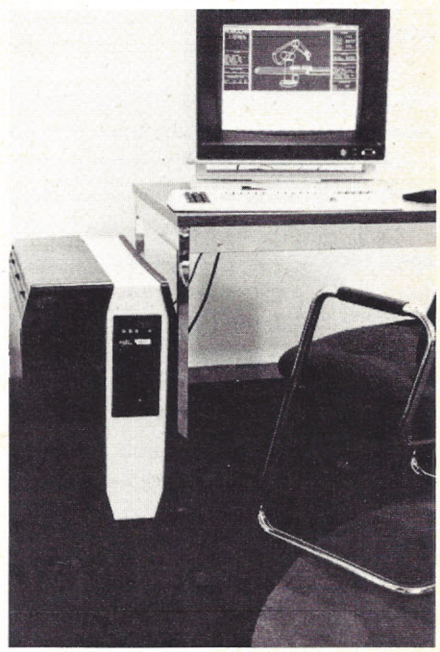

Photo 1. The CimStation has multiple-arm simulation capability.

easily modify the workcell layout, change the program, or even try out different robots. This process of modification and

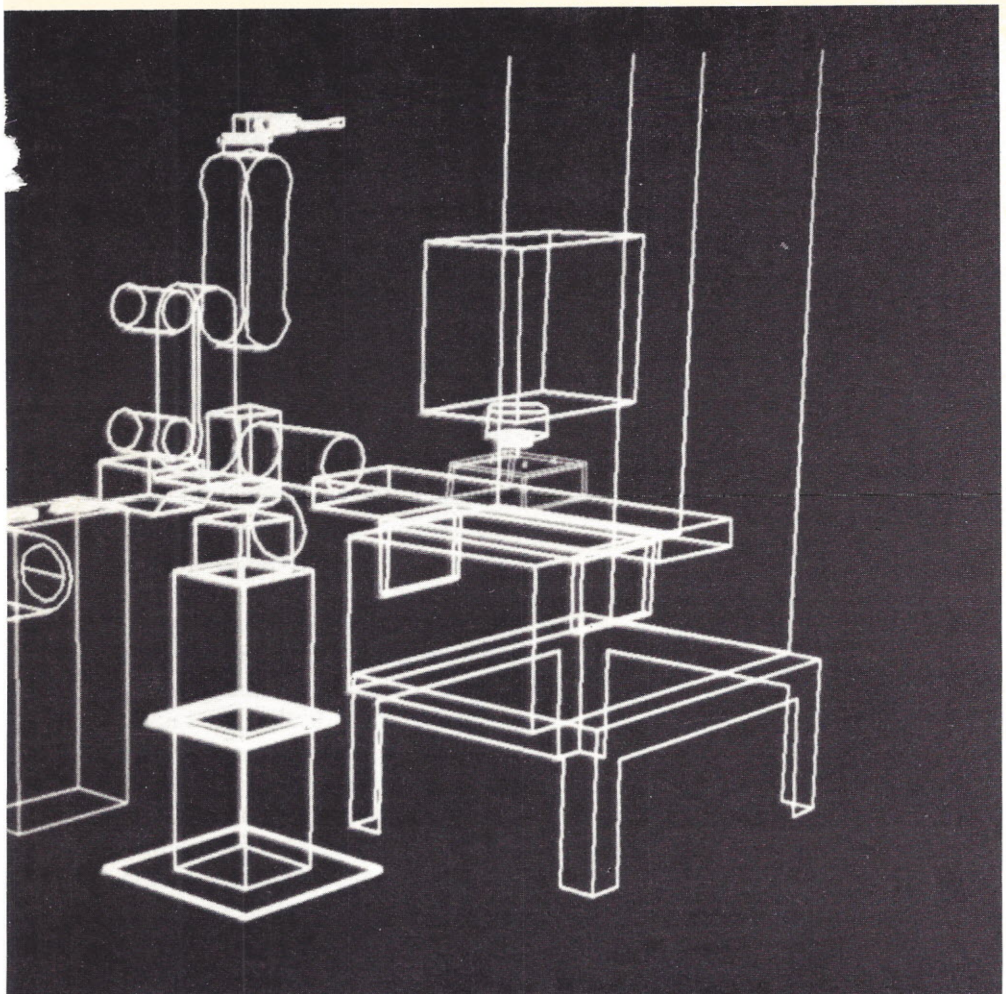

Photo 2. The robot shares its workcell with an NC milling machine, requiring tight communications to coordinate the task and to prevent collisions.

simulation continues until the designer is satisfied with the design, the choice of robots and other equipment, the system's cycle time, etc. Programs to drive the actual robot are also generated.

CimStation permits several robots to be present in the simulated workcell, along with vision systems, touch sensors, programmable controllers, NC machines, conveyance devices of various kinds, and so forth. The user generates not just one robot program, but rather a program for every robot and every other "active" device in the system. The programs contain not only commands to move arms and operate end effectors, but also commands for communication with other programs (simulating other devices) running concurrently. Communication takes place via signal and wait primitives. A program can signal information to another program, wait for a signal, or interrupt another program, temporarily redirecting its operation to an interrupt service routine. Data can pass from one program to another to simulate, for example, a vision system's passing position and orientation information to a robot. Among the devices that can be simulated is a programmable controller, whose program contains no motion commands but often includes exceedingly complex communication commands. There is no limit to the number of devices that can be present in the system.

Simulation provides a way to automatically detect and report errors of several kinds, such as goal positions out of reach, joint limit violations, and maximum acceleration/velocity limit violations. Other error conditions can be detected visually from the monitor, notably collisions and "close calls." Finally, simulation permits verification of the correctness of communications between devices. Programming of interaction between cooperating devices is notoriously difficult to get right. Subtle bugs are common and debugging is arduous and time-consuming. Simulation is a great aid to this kind of debugging because the turnaround time in running through a simulation, detecting a bug, and implementing a fix, is much less than the time required for on-the-floor debugging.

INTER-DEVICE COMMUNICATION

Even simple robot systems like the one depicted in Photo 2 require a surprising amount of inter-device communication. In this example, a robot picks up plastic blanks from a conveyor, loads them into a two-position fixture for milling by an NC machine, and later extracts the milled pieces from the fixture and palletizes them. The milling of one blank is overlapped by the palletizing of the previous piece and the pickup of the next blank. For maximum efficiency, the robot and the NC cutter enter and leave their common workspace just in time to avoid collisions, requiring tight communications between the robot and the cutter.

Additionally, the robot monitors signals from an optical sensor on the conveyor, from its own gripper, and from a pallet operator. It also issues signals to the conveyor and to a production control computer, as well as sounding a "pallet full" alarm for the operator. The communication for this system, really a rather simple one compared to many others, is diagrammed in Figure 1. The communication complexity compounds rapidly when multiple robots and tools operate in synchrony. Experienced robot system designers report that in elaborate systems, communication is often the main aspect to be debugged.

Simulation of multiple devices is made possible by a concurrent programming language that is the basis for CimStation. SIL™ (for the SILMA language) is an extension of Pascal designed for automation programming. SIL extends Pascal in two important ways: it includes primitives for concurrency, and it is implemented in a

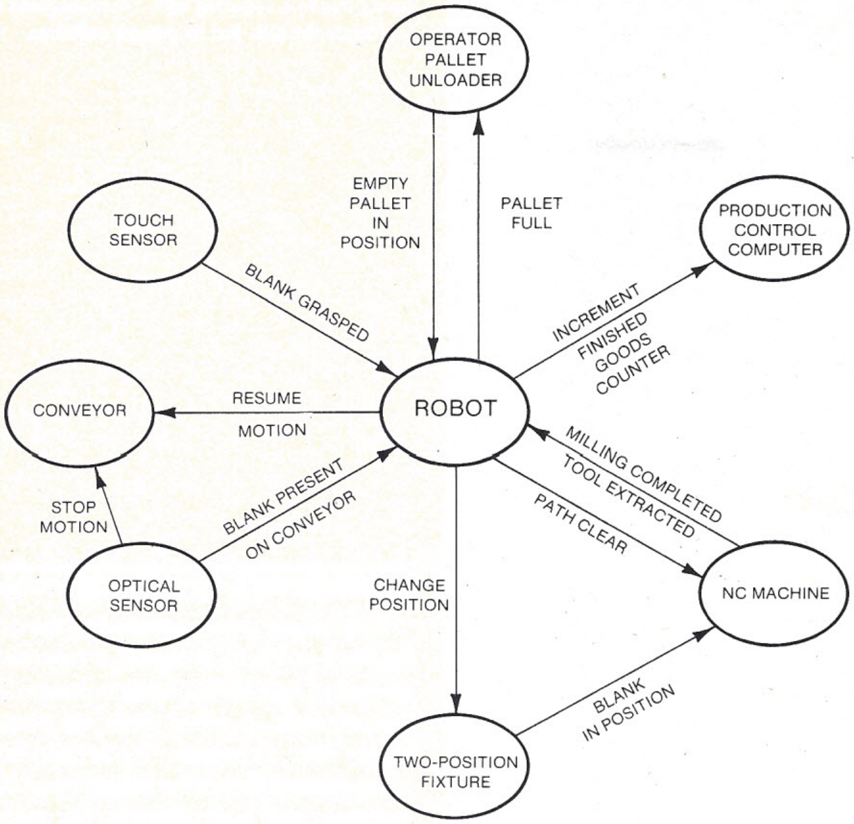

Figure 1. The robot avoids collisions with other machinery in its workcell by sending and receiving a number of signals.

fully interactive programming environment, like that of BASIC or LISP. Individual SIL commands can be executed interactively, with their effects immediately visible on the screen. Interactivity is very important for simulation purposes, because it allows the user immediate feedback about the effects of his actions. (The importance of interactivity for robot programming is well recognized; the majority of robot languages are interactive.) Alternatively, complete SIL programs can be compiled and run. Compiled SIL programs are as efficient as their Pascal counterparts. The usual penalty of an interactive system, namely, lack of efficiency for complex computations, is therefore not present in SIL.

CimStation can be extended by software packages that automate many of the difficult aspects of automation programming. For example, in particular applications, CimStation has been enhanced by algorithms which—in a sense appropriate to the application in question—automatically select the best scheduling of multiple arms from among a vast number of alternatives. A simulation capability thus can be regarded as an essential prerequisite for the automation of design and programming functions, as well as a tool directly employed by the human designer.

SIMULATING THE DYNAMICS OF MULTIPLE ARMS

True multiple-arm systems—those with overlapping workspaces and tight timing (Photo 3)—impose the greatest demands on a robot simulation system. Real robots follow complex paths in space as they move from point to point. Their speed of motion is generally compounded from trapezoidal acceleration/velocity/deceleration curves for each of their joints and they have built-in rules for choosing from among many kinematic solutions to reach designated goal points. Coarse approximations of the behavior of real robots may suffice for planning certain simple applications, but when planning intricate multiple-arm systems, such approximations can spell the difference between predicting and failing to predict collisions, between bottlenecks identified and bottlenecks missed, between performance rates known accurately and not known at all, between systems justified and systems never imple-

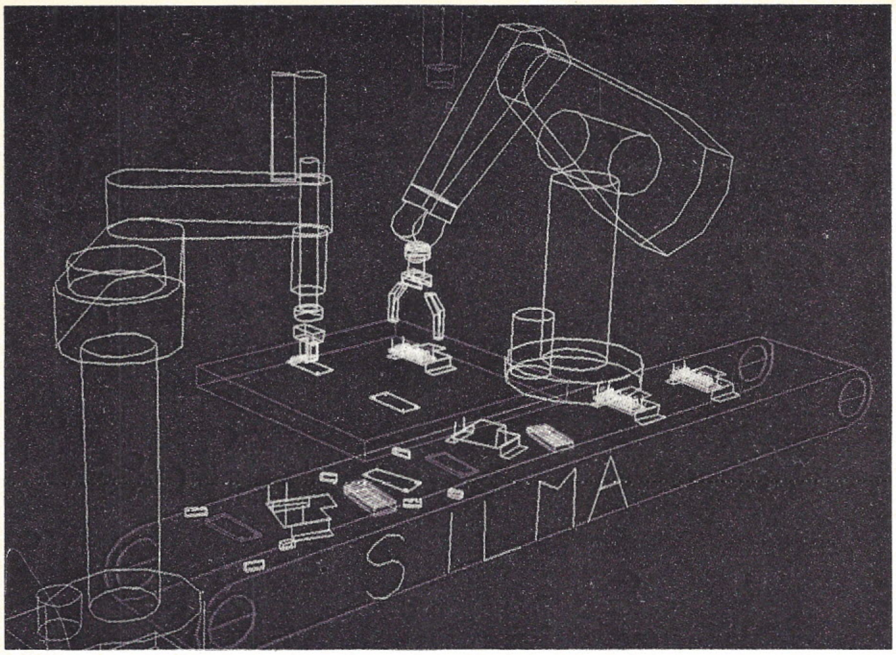

Photo 3. When designing a multiple-arm system, the algorithms for path planning and selection of kinematic solutions must be those used by the robot being simulated.

mented, and between systems that work and systems that do not. For all these reasons, it is imperative that the computer simulate robots the way they really work. Anything less is of little value.

A principal design goal of CimStation has been fidelity of simulation, a fidelity that requires that the same algorithms for path planning and selection of kinematic solutions be used in each simulation model precisely as they are employed by the robot being simulated. It is not sufficient to use generic inverse kinematic and path planning routines. Only a robot-by-robot approach will work.

CONCLUSION

The continued spread of robotic automation depends on successful implementation of more and more complex robotic systems. As complexity rises, the feasibility of on-the-floor programming decreases. In the not-so-long run, simulation will become not just a convenience but a necessity for making the design and programming of complex multi-robot workcells possible.

James F. Callan is a Vice President at Silma, Incorporated.

Reader Feedback

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4	14	24
Excellent	Good	Fair

Case History of an Automated Assembly System

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When Xebec decided on a printed circuit board testing, storage, and bracket assembly system for its Gardnerville, Nevada, facility, it contracted FARED Robot Systems to design, develop, build, and install it. This system was to handle several board types simultaneously and receive boards from the manufacturing facility on demand, meter them to automatic test stations, repair stations, and board trim and bracket installation stations (Photos 1 and 2). The flow diagrams were developed in conjunction with Xebec's engineering staff to meet its preferred sequence of operations and throughput. A Wiebe Systems programmable distribution system for part transportation, IBM 7540 robots, and FARED proprietary board totes, board handling, and FARED-generated custom software were the major elements used in this application.

A typical testing cycle is as follows: the Wiebe system indicates a tote is shot pinned in the working-good-part location, and that another is shot pinned in the reject tote location. The robot searches for a board, and, locating one, removes it. It changes the board from a vertical to a horizontal position and locates it on testers that have been modified with extended pins. The robot then signals the tester to lower the lowerator platform, turn on the vacuum, and initiate the appropriate test.

If the board under test is defective, it is removed and the robot presents its barcoded label to a stationary bar code reader. The serial number is transmitted to the SC1-1033, a FARED information multiplexer, and the error code is requested from the tester. The SC1-1033 merges the two pieces of information and both are sent to the PC host for retrieval during repair. The load and unload cycles are each 12 sec. and the scanning cycle is 9 sec. If a board is misplaced in the grippers, or will not load into the tester or a tote, it is placed in a holding area. Using adaptive assembly and error recovery techniques, machine stoppages have been designed out as often as practical.

Accepted boards are stored until needed for shipping. Bad boards are also stored during first shift, lunch breaks, and any second-shift or third-shift operation, which allows three-shift testing and single-shift debugging and repair. When shipping personnel are available, the system sends good boards from the storage area to a bracket installation station where the boards are removed from the tote and a mounting bracket is installed. After the bracket is installed, a processing tab is sheared from the face of the board and the board is sent to a packaging station.

The PC board testing line (Photo 3)

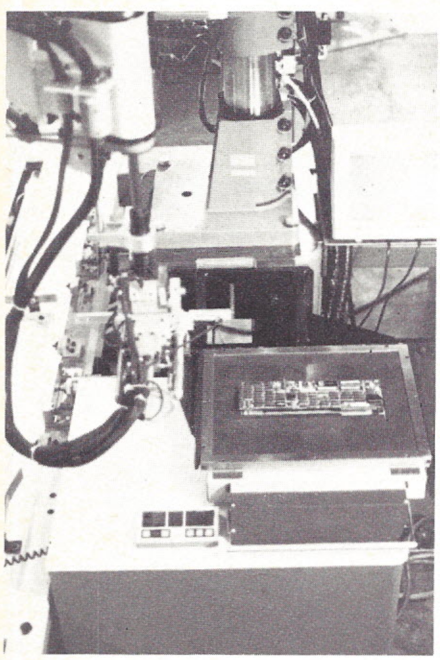

Photo 1. The robot picks up a printed circuit board, rotates it, places it onto a tester, and finally puts it into an accept or a reject tote.

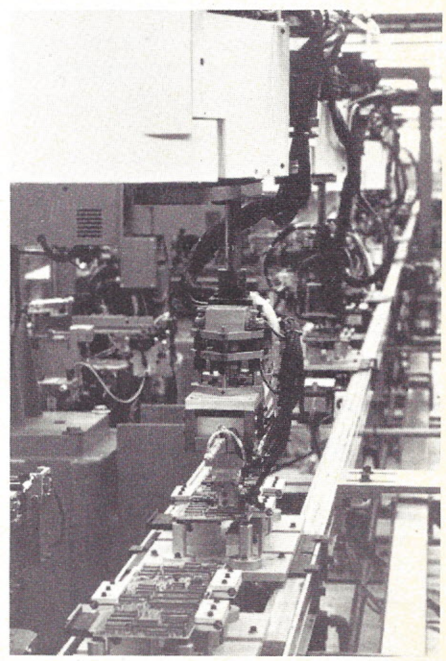

Photo 2. The multi-station circuit board assembly system includes feeding and lead-forming tooling for a variety of odd-form electronic components.

presents new problems for robotics. The robot must cover the full working envelope of functional testers, short circuit testers, and large transport totes, and still maintain repeatability and accuracy. Larger boards present an additional problem—the part does not easily provide a flat plane. Board warp and planar distortions were the most difficult problems to solve.

All boards are loaded into a custom tote after wave solder and inspection. All totes from the solder station are directed to the storage rack. The storage rack can function in a FIFO or LIFO method; this installation uses FIFO. From the storage rack, which can hold 300 totes with 14 or 30 boards each, an Allen-Bradley Series 230 or 2/05 PLC directs totes to work stations on demand. A zone control feature used by Wiebe makes tote identification unnecessary, in that it allows the user to define work zones and single totes to pass through one zone at a time; the result is considerable savings on a tote ID system.

The workcells on the distribution system are identical, regardless of function. Each contains a filled tote with boards to be tested and an empty tote for rejects. The available slots in the reject tote are electronically stored, to be released when full or if an operator at a repair station requests more work. The totes supplying boards to be tested are assumed full, but only a small cycle time penalty is incurred if a slot is empty. The totes are always locked in place for robotic work.

One of the key features of this system is the tote currently being tested. It consists of two distinct parts. An outer plastic box open on the top allows transportation without any board contact. The inner section of the tote, which is completely independent from the outer shell, is an aluminum frame with slots milled in the sides. This frame also contains four shot pin receptacles. These seats allow each tote to mate with corresponding shot pins driven by the stop stations. Shot pinning the frame is the only way to guarantee repeatable tote location. The milled slots also ensure that all boards are spaced on precision centers. The design goal was PC board location within ± 0.015 in. FARED found this precision less costly than a vision system interface for slot location; without this precision control, an unacceptable number of misses will occur.

The robot support is a precision-machined casting. The transport, testers, and any other peripheral equipment are attached to this stand. Precision casting defines the robot's world coordinate system, allowing maintenance of accuracy and exchange of components without reteaching the entire robot program. The IBM robots used in this system offer the accuracy and repeatability necessary for the task. The "Z" stroke was modified to allow 15 in. of movement, thereby providing adequate stroke for board removal from the tote. The IBM 7540's mean time between failure of 2000 hours was instrumental in selection of this machine. It also fulfills all the other selection criteria outlined in the PC board assembly system.

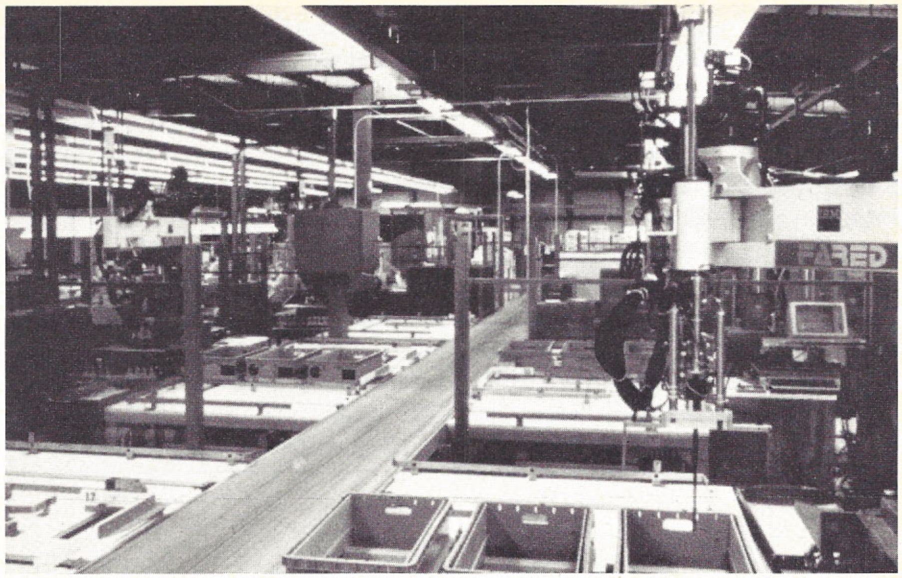

Photo 3. On the testing line, the robot covers the full working envelope of functional testers, short circuit testers, and transport totes while maintaining repeatability and accuracy.

The gripper design is a patented device developed at FARED, consisting of two moveable side guides that are driven by a precision parallel gripper to ensure proper centering of the board. Another stationary guide is placed at the top of the board. An independently driven loading tang pulls the board out of the tote and into the side and top guides. When the board is pulled into the guides, sensors indicate proper board placement and the side guides close, centering the board.

To facilitate unloading the board into the tester, two modifications were made to the bed-of-nails test head. First, FARED extended the guide pins 1 in. to allow the robot to load the board directly onto the pins. Then the bed of nails was fitted with a small elevator-lowerator platform to provide a consistent placement and pickup location for the robot. To unload the board into a tote, the side guides are released while maintaining their guide position and pushing the board into the tote slot until it is fully seated. The gripper used many sensors to confirm each action and the presence of the board. It is mounted on a tool changer that interconnects all air and electrical connections. In this test system two boards were run concurrently, making the tool changer mandatory.

System control involves a three-level hierarchy. The robots control everything inside their work area. If any control functions are required that the robot controller cannot supply, the cell's needs are supplied by the Allen-Bradley PLC or the host IBM PC. Communications to these devices are handled serially via RS-232 to the IBM PC or digitally to the Allen-Bradley PLC. Services needed from the computer are coordinated by the robot controller. The robot stations are designed to be as autonomous as practical. If the PC goes down or is taken off line, the system carries on.

All serial communications are handled by a multiplexer, the FARED SC1-1033. Each line is buffered and the multiplexer also functions as a cross-compiler. This allows all serial communicating devices to be networked in near real time. The main console display prompts the operator with error messages and diagnostic information. The host also records operating statistics such as system run time, number of parts produced, the performance of each cell, the number of rejects cell by cell, the average cycle time of the board repair operations, and so forth. The multiplexer enhances the system by allowing orderly startup and shutdown. The user can address each robot or ancillary device individually or concurrently, giving the console operator complete control. Information is passed on to an IBM-supplied CIM system that generates management information as required.

This system, and others like it, are in the vanguard of new options available to electronics manufacturers. As the electronics and communications industries continue to expand rapidly, fierce competition is forcing profit margins down. Robotics offers the cost-effective edge necessary to make the high quality/low-cost products the marketplace demands.

Frank C. Romeo is Executive Vice President of FARED Robot Systems, Inc.

Reader Feedback

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5	15	25
Excellent	Good	Fair

Edited by Stephanie vL Henkel

SCIENCE & TECHNOLOGY

A growing demand from end users that the robots they buy live up to manufacturers' safety and performance specifications has given rise to a number of research projects and robot evaluation facilities. The National Bureau of Standards and Selcom (see *Robotics Age*, June 1985, p. 38) have been joined in their verification efforts by **Underwriters Laboratories Inc.**, the **Robotic Industries Association**, the **Industrial Technology Institute**, and **Worcester Polytechnic Institute**'s Manufacturing Engineering Applications Center.

UL is offering a testing service designed to establish its proposed Standard UL 1740, which covers robotic systems intended for indoor use in industrial applications including welding, paint spraying, assembly, parts transfer, inspection, die-casting, and deburring. The standard contains construction and performance requirements intended to reduce to a reasonable safety level hazards such as electrical shock, fire, and casualty. To evaluate the effects of voltage transients, defined electrical surges are imposed on a robot system's electrical input while the robot is under normal operation. An abnormal test is used to determine the effects of power loss and restoration. The robot is also given an overload test in which an arm/payload combination exceeding design qualifications is moved through its designated work envelope. Component evaluations are also performed on electronic safety circuits such as the speed-reduction circuitry and other motion controls, and object presence detectors. Robotic systems intended for use in locations defined as hazardous by the National Electrical Code must already comply with UL 913, the Standard for Intrinsically Safe Apparatus and Associated Apparatus.

The RIA has also been drawing up the first proposed American National Robot Safety Standard and will present the proposal at a seminar to be held in conjunction with Robots 10 in April. The standard, expected to receive official approval from the American National Standards Institute, outlines steps for the safe construction, installation, care, and operation of industrial robots and robot systems.

The Industrial Technology Institute, a not-for-profit corporation established to improve American industrial productivity and competitiveness, has for some time made available to its clients a variety of services in automated manufacturing technologies. ITI recently established a Robotic Evaluation Center (REC) in Ann Arbor, Michigan to provide robotic performance evaluation, application consulting and engineering, R&D, and training. Using Selcom's SELSPINE Robot Check System, REC conducts a set of standard evalua-

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tion tests: point-to-point, including repeatability, cycle time/velocity, maximum velocity (slew rate), settling time/overshoot/undershoot, and hysteresis; continuous path, including circular interpolation, linear interpolation and cornering capability, and accuracy; and, finally, tests of cycle time and duty cycle. Customized evaluations can also be developed, such as specific application evaluations, detailed robot characteristics, and safety tests.

In a report from Worcester (Massachusetts) Polytech's Manufacturing Engineering Applications Center, Ulrich Griebel and Richard A. Higger note that "most state-of-the-art [robotic] position measuring systems will determine deviations in discrete locations, e.g., at the end of a programmed path, but will not provide any information about how this position was reached." The researchers have devised a measurement system that uses five linear proximity sensors and one optical sensor incorporated in a measuring head that is attached to the robot arm. Six independent coordinates can be monitored in reference to a fixed steel gauge during the robot's travel. Maximum linear travel on the system used for the project is 39.4 in., maximum travel speed is 39.4 in./sec., and the resolution of a single sensor is better than 0.0004 in. The analog sensor outputs are converted to digital values via a data acquisition board and are transferred to a microcomputer for data analysis, display, and storage. The system has been designed for adaptability to almost any robot currently available on the market.

MARKET RESEARCH

Figures released by the **Robotic Industries Association** at its annual meeting in January indicate that shipments by U.S.-based industrial robot suppliers rose by 81 percent in dollar value and by 34 percent in units in the third quarter of 1985 over the same period in 1984. A total of 1789 units, valued at $156.9 million were shipped, compared with 1336 at $86.9 million in the comparable quarter of 1984. In the third reporting quarter of 1985, total shipments were 4553 at $299.8 million; 1984's third-quarter report set the number at 3633 units at $234.9 million. New orders also showed significant rises, up 71 percent in dollar value and 33 percent in units, with an order total of 1636 units valued at $117.6, up from 1260 at $75.7 million. Unfilled orders were 2591 at $374.6 million for the first three quarters of 1985, up from 1984's 1578 at $131.1 million. The RIA estimates that more than 20,000 robots are now in use in the U.S. The organization also announced

Advertising

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that it would move from Dearborn to new headquarters in Ann Arbor, Michigan. The relocation is expected to be complete by February 28.

A new report from **The Freedonia Group** of Columbus, Ohio predicts that U.S. sales of robots will increase over 20 percent/year and reach $3.25 billion by 1995, with an installed base of 109,000. The report goes on, however, to identify existing and anticipated snags in the growth picture. Despite the "great promise" of GMF's Manufacturing Automation Protocol, an industry-wide communications standard has yet to be established. The incorporation of robots requires that the factories, the production processes, and even the parts used must be adapted to the robot, a potentially costly changeover in terms of product redesign, new tooling and fixturing, changes in plant layout, and software development. Further, the projected growth rate is lower than the forecasts of the past several years and well below the historical growth of 40 percent. On the brighter side, resistance on the part of workers, previously expected to present a significant barrier, has not greatly inhibited the adoption of robotics, the report continues. Sizable opportunities exist for arc welding, palletizing, machine loading, assembly (especially small-parts), and inspection robots. Parts and attachments will become important as the installed base expands and as a replacement market emerges. Spot welding, parts transfer, and parts finishing robots will experience more subdued growth (about 12 percent/year) because these robots have reached a more advanced degree of market maturity. Although prices of many electronic components and subassemblies are declining, many other parts going into robots are rising in cost, leading to an anticipated rise in average robotic unit prices of over 4 percent/year. While U.S. suppliers are retaining their competitive advantages in technology, quality, availability of equipment and spare parts, and marketing and technical service support, they are unable to compete on price and maintenance costs. Foreign suppliers will continue to strengthen their foothold in the U.S. market, and by 1995 a net import position of $225 million (about 7 percent of sales) can be expected. Joint ventures between U.S. and foreign (mainly Japanese) robot suppliers will grow in importance. The robotics industry has experienced a shakeout and is now composed of about 75 companies, of which only about 45 provide complete robotic systems. The rest supply parts and attachments and other peripherals. Robotic suppliers are beginning to incorporate a systems approach that is more adaptive to end user needs. Successful competitive strategies include product differentiation via technological exclusivity and market segmentation along robot type or end user lines. The factory automation companies will have the financial, technical, and marketing resources to provide a complete application package to the end user, the report concludes, and the smaller firms will find market niches or will service the larger firms and the factory automation consultants.

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BOOK REVIEWS

Introduction to Robotics, Mechanics and Control. By John J. Craig. 300 pages. Addison-Wesley. 1986. $36.95.

The preface of this book is good, accurately outlining the work to be developed in mechanical manipulation, discussing the background requirements for students to use the book, and explaining briefly the contents, chapter by chapter. Unfortunately, the publisher's flyleaf is overblown—"Until now, good teaching material for this emerging technology [robotics] was lacking. Here at last . . ." The first part of this quotation may be correct; the second is not.

I have an aversion to photographs in books when they add no useful information and act only as fillers. The subject of Craig's book is so vast that he could have used space in this 300-page book more advantageously.

The initial specification of robot joints is imprecise, incomplete, and potentially ambiguous, in spite of the accompanying diagrams. What is a prismatic joint? Not all types of robotic joints are considered. This lack of definition infects that description of joint space and Cartesian space, and manipulator dynamics. The *lead-up* to the specification of rotation matrices is fine as far as it goes, but the reader is left to infer the matrix

$$\begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

a result developed by Richard Paul [*Robot Manipulators,* MIT Press, 1981], before considering an example of its use. One of the failings of Paul is that he tends to plunk underived formulas on the reader's lap. Craig, who derives much of his inspiration from Paul, inherits this trait.

The kinematic analysis of some commercial robots is useful material. The references given are appropriate, but scarce—more are needed. The definition of solvability for the inverse kinematic solution of a robot is troublesome, since all robots are solvable. Craig is not correct when he states that "only in special cases may robots with six degrees of freedom be solved analytically."

Craig's definitions of dextrous and reachable workspace are very useful guides in path planning. The trajectory planning chapter, too, is interesting, and it would have been nice to see more of this. Unfortunately, this book is a series of samplers with too little information on each to satisfy, so to base a college course on this text would be difficult.

It is probably unfair to expect an introductory book to include a significant amount of new material. Eighty percent of robotics books are at the gee-whiz, popular level. This book lies in the other 20 percent. It could be useful for someone with an analytical, science-based background just entering the field of robotics. But for those of us with a small library of robotics references, the book does not contain enough new information to warrant its expense.

Robert E. Parkin, Ph.D.

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Robot Hands and Mechanics of Manipulation. By Matthew T. Mason and J. Kenneth Salisbury, Jr. 298 pages. MIT Press. 1985. $30.00.

Books in the MIT Press series in artificial intelligence never lack information, and Mason and Salisbury's work is no exception. As always, it is clear that any author in this series has performed the work, achieved the results, and become the expert.

I applauded Salisbury's statement in the first chapter: "In performing the kinematic analysis our approach has not been to survey desirable human functions and try to emulate them. Rather we have taken a more abstract kinematic viewpoint."

In this work, the photographs are informative and appropriate. Diagrams of the mechanism of the Stanford hand are followed by photographs clearly showing the gripping action of the hand. The sizing of figures containing the same amount of information varies from very small to jumbo. One has the impression that MIT Press rushes a manuscript through with less regard for graphics than other publishers, but this permits a work to hit the streets faster, and so is beneficial overall. Some of the penalties paid by the reader are diagrams not on the same page as the corresponding text, and poor editing (Figure 2 on page 114 is the same as Figure 3.1, and diagrams on pages 29, 115, and 155 are the same).

The work uses references appropriately and extensively, reinforcing the impression of scholarship. Occasionally, the research nature of the material makes it more like a paper in a technical journal than a book. For example, the Pluecker line is used without definition (but properly referenced) on page 16, leaving the uninitiated reader scrambling for cover. This work is not a textbook, and as such will probably not be adopted in college courses: it is a monograph that will be required reading for all who are engaged in the analysis and design of noncompliant robot hands.

It is interesting to note that the more advanced books in robotics demonstrate how little we know about robotics. Trivial books imply that we can do almost anything. Mason and Salisbury prove how little we know and how much more work there is to do. Take heart, budding researchers: here is lifelong job security. REP

CALL FOR PAPERS

The **IEEE Computer Society** will sponsor an international conference on computer aided design the week of November 10–15 in Santa Clara, California. Topics to be addressed include design synthesis, CAD systems, interactive graphics, modeling and simulation techniques, design automation, expert systems, layout and layout verification, testing, and hardware accessories. The due date for abstracts is May 9, 1986. Papers should be submitted to ICCAD-86 Secretary, AT&T Bell Laboratories, 1247 S. Cedar Crest Blvd., Allentown, PA 18103, telephone (215) 770-3485.

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PEOPLE

► **Clifford R. Meyer,** president of **Cincinnati Milacron,** retired on December 31, 1985, for health reasons. He had been with the company since 1956, filling positions of steadily increasing management responsibility before being named president and CEO in 1982. Meyer's duties have been assumed by **Donald G. Shively**, who joined the firm in 1957 and was made executive vice president–operations in November, 1985.

► **Philip E. London** has joined **Cognition, Inc.** as vice president of expert systems and company founder. Dr. London, who holds a Ph.D. in computer science, joins an existing team of nine cognition founders led by Philippe Villers, company president. He was previously associated with Teknowledge, Inc.

► **Peter Chiasson** has been named president and CEO of **Alsys, Inc.** He will also serve on the board of directors of both Alsys and its parent company, Alsys S.A. of France. Chiasson was formerly with the Electronics Division of Computervision Corp.

CORPORATE NEWS

► **Allen-Bradley** has adopted **Karel**, developed by **GMF Robotics,** as the standard application language for programming A-B's new robotic control products for industrial automation systems. (For more about Karel, see *Robotics Age*, September 1985, p. 10).

► **GMF Robotics** has announced what the firm terms an industry first—using robots to produce robots. The new Computer Integrated, Flexible Manufacturing System will be used to manufacture GMF's P-150 electric painting robots, which have developed a $60 million backlog since their introduction last June. The new system is scheduled to go into operation early next year at GMF's technological development center, currently under construction in Rochester Hills, Michigan.

► **Advanced Assembly Automation, Inc.** has merged with **Fabrication Specialties Company**. The FABSPEC line of robotic positioning equipment will be manufactured in Advanced's facility. An additional $1 million in equity has been infused for a minority interest in the corporation.

► **IBM** and **Industrial Networking, Inc.** have entered into an agreement to jointly develop MAP products. INI, a joint venture company between Ungermann-Bass, Inc. and GE, was the first Local Area Network manufacturer to offer board-level interfaces capable of supporting the entire MAP specification. According to INI president and CEO Joseph P. Schoendorf, initial development efforts will be focused on the industrial computer family.

New Products

Winchester Disk Drive Option Is Available for CIM Operations

A 10-Mbyte Winchester disk drive option from GCA can store and access large numbers of programs and data files in the firm's CIMROC® 2 robot controllers and the CIMCON™ controllers and CIMPREP™ workstations. The drive is shock-mounted inside the controllers during field installation. A floppy-disk drive option is required before the Winchester drive can be installed; the floppy drive option package includes a 308-Kbyte drive with locatable drive door, file handler software, and five 3.5 in. diskettes. The disk file handler software accesses either drive, and the floppy drive can be used to archive programs from the hard disk.

For more information, contact: Elan Long, GCA/Industrial Systems Group, One Energy Center, Naperville, IL 60566, telephone (312) 369-2110. Circle 100

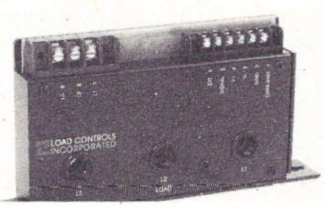
Four-headed Dispensing Robot Lays Two Different Materials

The QuadraSpenser™ is said to be the world's first automated dispensing system; it is capable of applying two different materials at 1200 in./min. in two different complex patterns. Developed by Robotics, Inc., the system is based on a Cartesian coordinate robot with Allen Bradley Series 8200 controllers. The QuadraSpenser is gantry-mounted and has a 10 by 11 ft footprint.

Currently in use at two automotive stamping plants, the system uses two of its heads to lay a structural bonding material around the perimeter of a car hatch gate and the other two to apply an anti-flutter/sound-deadening mastic in a dash pattern to the interior contact points between the hatch gate's inner and outer panels. The bead path totals nearly 350 in., and the cycle is completed in 8 sec. Repeatability is ± 0.010 in.

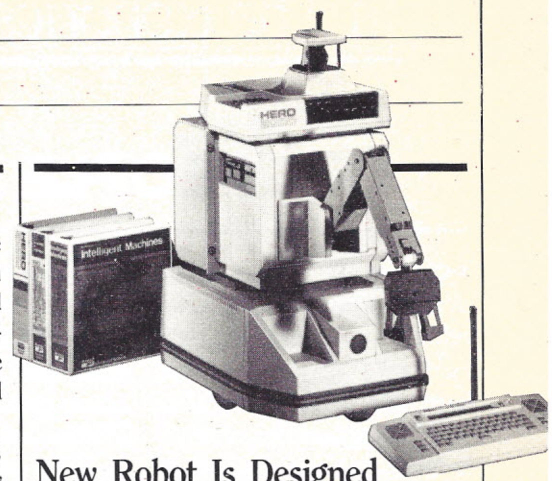
For more information, contact: Robotics, Inc., R.D. 3, Rte. 9, Ballston Spa, NY 12020, telephone (518) 899-4211. Circle 101

Power Cell Incorporates Hall-effect Transducers



Hall-effect transducers in Load Controls' new power cell sense variable frequency, fixed frequency, and DC power. Outputs available are 4–20 mA, 0–1 mA, 0–5 V, and 0–10 V. The output is linear and electrically isolated. The power signal can be used as an input to computers or programmable controllers. It can drive meters, displays, and chart recorders. The power cell can also be connected to LCI load controls for machine or process control. Capacity can be changed in the field to match the load and to maximize sensitivity.

For more information, contact: William H. McClurg, Load Controls, Incorporated, Technology Park, 10 Picker Rd., Sturbridge, MA 01566, telephone (617) 347-2606. Circle 102



New Robot Is Designed for Industrial Training

The newest addition to Heath's robots, the HERO 2000, is said to simulate virtually every automation process currently in industrial use. The educational package covers the concepts of robotics, process control, factory automation, CAD/CAM, and computer-machine interfacing. Three courses of instruction are available for use with the robot.

HERO 2000 is 32 in. tall and weighs 78 lb., including the arm. All operating systems are controlled by a 16-bit master processor. The robot's drive, and torso and arm movement are powered by eight closed-loop DC servomotors. Eleven 8-bit slave microprocessors under master processor control permit simultaneous I/O functions. On-board ROM is 64 K and includes a specially enhanced BASIC as well as demonstration programs, direct text-to-speech conversion, and diagnostic routines. With optional accessory boards, on-board RAM can be expanded from 24 K to over ½ MByte. Other features include a remote console with an RF link that permits control and programming from up to 100 ft away and two sonar transducers that sense objects and movement up to 10 ft away. The head-mounted sonar unit scans 360 degrees, while the base unit points straight ahead.

For more information, contact: Heath Company, Department 570-506, St. Joseph, MI 49085, telephone (616) 982-3210. Circle 103

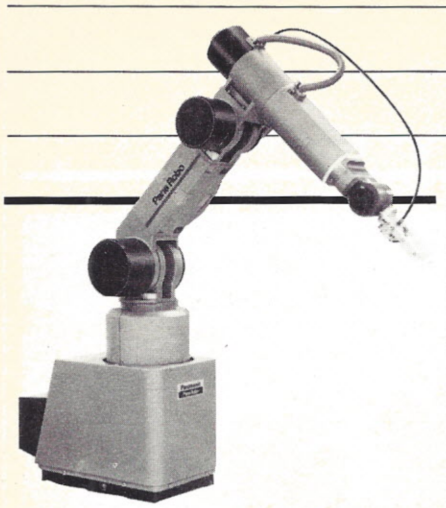
Laser Probe System Is Designed for End Effector Mounting

A miniature noncontact laser probe designed to measure parts to an accuracy of $\pm$ 0.0005 in. is available from Candid Logic. The Mini-Precimeter weighs 4.75 oz. and measures 3 by 2 by 5/8 in. It combines a laser beam and a triangulation principle to determine the precise position of virtually any working surface at a standoff distance of 3.5 in. It has a measuring range of 1.25 in.

Designed for use on robotic end effectors and CMMs, the system allows for location, dimensional measurement, and qualification of complex parts without distortion. The unit measures metal parts and also soft or fragile items such as rubber, clay, and liquids. In addition to the Mini-Precimeter, the system includes a power supply and a microprocessor control unit for signal processing.

For more information, contact: Candid Logic, Inc., 31681 Dequindre, PO Box 71943, Madison Heights, MI 48071-0943, telephone (313) 583-9266. Circle 104

New Products



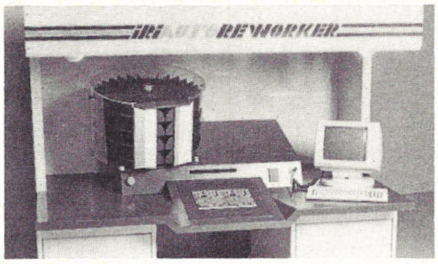
Plastic Processors Are Offered Full Robotic Systems Integration

Application Automation (an AEC company) has added the Panasonic line of robot systems to offer post-molding assembly, inspection, and packaging functions, as well as automated parts removal to plastics manufacturers. The robots move at up to 126 in./sec. under microprocessor control to perform complex fastening, component insertion, coating, and part-orientation tasks. They can accept user-specified quick-change end-of-arm tooling. Optional RS-232 communications permit interface to PCs or other controllers. A sequence module is available that supports system expansion to CIM.

The robots range from 2-axis pick-and-place to 6-axis, vertically integrated units. Reach is up to 20 in.; swing up to 270 degrees; adjustable velocity control, repeatable closed loop servopositioning accuracy up to ± 0.002 in., and load capacity to 11 lb. Control system features include teach mode, digital timing functions, internal IC memory with battery backup for storing up to 1000 program steps, and up to 10 inputs and 11 outputs.

For more information, contact: Application Automation, 850 Pratt Blvd., Elk Grove Village, IL 60007, telephone (312) 593-5000.

Circle 105



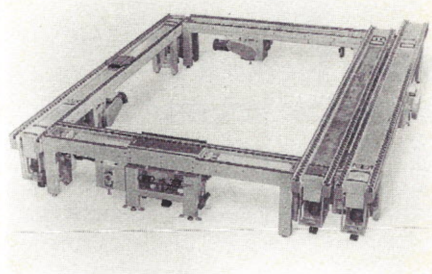
Workcell Series Is Designed for Electronics Manufacturers

The Inspector Workcell Series from IRI is designed for the electronics/electrical manufacturing process. Its modules, which can be user-specified, are: the Auto Inspector, providing SMD, through-hole, OCR, post-solder, and bare-board inspection; the Auto Reworker (shown), with a database link, providing a board repair station with calibration, parts presentation, laser guidance, vision verification, and board identification; the Auto Trainer, providing online/offline, boards/parts, CAD, and manual training and editing; the Auto Handler, providing materials handling, inspector loading/unloading, and robot routing; the Auto Supervisor/Reporter, providing management reports that include part/board error analysis, product tracking, report generation, job/order status, and part purging; and the Auto Networker, providing computer/network communications to CAD/CAM databases, accounting data, materials planning, production planning, and quality control information.

The products can be configured to specific applications by using fixed and/or moving lights and cameras, multiple vision systems, multiple processors, and robotic controllers.

For more information, contact: Chuck Giordanella, International Robomation/Intelligence, 2281 Las Palmas Dr., Carlsbad, CA 92008, telephone (619) 438-4424.

Circle 106



Transporter System Adapts to Individual System Requirements

The ACCU-Wheelveyor Transporter from I.T. Equipment is an open-centered, nonsynchronous, linear, assembly conveyor system with modular design and programmable sequences that allow standardized trays or pallets to be moved along a controlled path. The device can be interfaced with robots, storage/retrieval systems, AGVs, and other automated machinery. Various sizes of power and free chain are available to suit load conditions and sizes.

Open center dimensions and individual conveyor lengths are flexible to adapt to individual system requirements. Center drives eliminate restrictions caused by end drive locations. The open center provides central access to the unit load; workstations, right-angle transfers, positioning devices, turn tables, and other devices offered as accessories can be fitted into the basic transporter lines. Drives, pneumatic components, and controls are available in various domestic brands to meet client requirements.

For more information, contact: George A. Avon, Jr., VP Marketing, I.T. Equipment, Inc., 1147 Mishawaka Ave., South Bend, IN 46615, telephone (219) 282-2381.

Circle 107

Pressure Switches Are Suitable for Pressure and Vacuum Sensing

The 890-0010 series of pressure switches from Robitech are said to eliminate the need for two different switches for either positive or negative pressure-sensing applications. The switches employ a sealed metal bellows pressure sensor that is not subject to the temperature sensitivity, sticking, or wear associated with sliding piston switches. A phillips head screw provides trip point setting

with greater than 1 percent FS repeatability, from 0–90 psi or up to 28 in. HG. The O ringed 10–32 NF male thread port connection makes a positive seal and can be adapted to 1/8 in. standard pipe for system retrofitting.

The internal SPDT snap action switch is rated for 5 A, 115 VAC, or up to 28 VDC. A 0.1 in. spaced, prewired amp type connector permits plug-on jumper connection. Applications include robotic process control and factory automation.

For more information, contact: Philip Surette, Robitech, Inc., 10 Upton Dr., Wilington, MA 01887, telephone (617) 657-6143.

Circle 108

New Products

Robotic Workcell Is Designed for Industrial Training

A new addition to the Rhino XR Series of robotic training systems is the FG1331, a workcell that integrates the Rhino robot with the following accessories: XR Series robotic arm, Mark III controller, teach pendant, RoboTalk software, linear slide base, rotary carousel, belt conveyor, workcell order center, vertical conveyor, ball sorter, inspection station, pallet return ramp, base, base support, and mounting accessories.

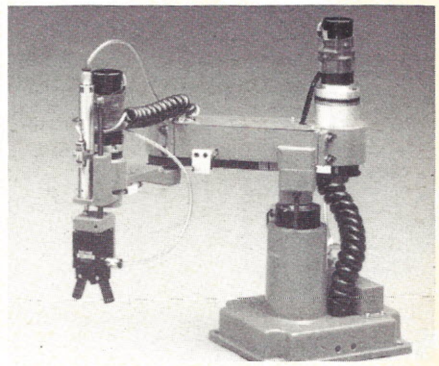
The height of the workcell is 40 in., and its floor space requirement is 42 in. It runs on 120/240 VAC, 775 watts, 50/60 Hz. A comprehensive manual is included, as well as manuals for each main component.

For more information, contact: Rhino Robots, Inc., 3402 N. Mattis Ave., Champaign, IL 61820, telephone (217) 352-8485.
Circle 109

Servo Robot Performs High-Speed Parts Handling

A SCARA DC servo robot available from ATP, Inc. is said to offer high-speed parts handling at a lower price than other robots with the same capabilities. The 88-4SR is designed for assembly and electronic component insertion. Its three DC servos with digital optical encoders and harmonic drive reducers offer position repeatability and accuracy up to ± 0.0004 in. The robot has a reach of 12 in. and moves at combined speeds of 32 in./sec. It can be equipped with an optical 8 in. or 16 in. horizontal running unit to increase its work envelope.

The 88-4SR features a 6-program storage capacity, with 78 set points each, to provide up to 468 total set points. An RS-232 interface allows linking of a host computer for unlimited program capacity, loading, editing, and saving. A sequencer interface for I/Os allows access through the user's programmable controller. Other optional accessories include air and vacuum end effectors and software for PCs.



For more information, contact: ATP, Inc., 2451 Baseline Rd., Grand Island, NY 14072, telephone (716) 773-0972.
Circle 110

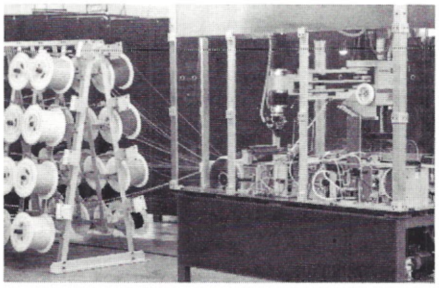
Robotic System Can Kit Wires

Gelzer's new Model RWP (Robotic Wire Prep) prepares and kits wires in sequence for cable harnesses and complex jumper and connector sets. Designed primarily for small lot

Circle 54

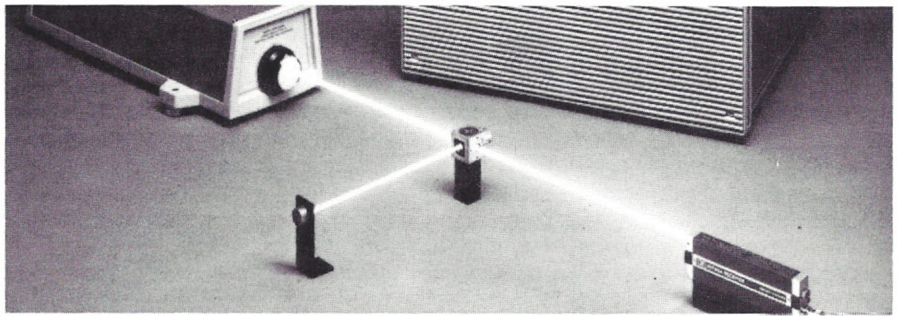
applications, the robot can produce a tape of finished wires that have been cut to length, stripped, tinned, and terminated.

The current model accesses 40 wires of different gauges and colors, selecting the right wire in sequence, pulling it to the correct length, and capturing and cutting the other end—using only one gripper. The wire is then taped with the free ends on one side of the tape,



which then advances through multiple stations for stripping, tinning, and terminating prior to the final packing operation.

For more information, contact: Gelzer Systems Company, 4199 Weaver Ct. South, Hilliard , OH 43026, telephone (614) 771-0117.
Circle 111



Laser System Improves Monitoring of Precision Equipment

A new laser position transducer from Hewlett-Packard, the HP 5527A, is said to improve submicron position control and monitoring of precision equipment. The system consists of five modular components: a laser head that features a 2-frequency design and allows several axes of measurement; measurement optics that consist of an interferometer and a reflector that generate optical-measurement information when motion occurs between them; splitting and bending optics that divide and direct the laser beam for multiple-measurement axes and various measurement configurations; optical receivers that translate the optical-measurement signal into an equivalent electrical signal; and new electronics that provide position information for position monitoring and feedback.

The system can resolve linear-position measurements of 4 nm at velocities of up to 40.6 cm/sec. Control for closed-loop systems is a 1.5 MHz position or position-error update rate. Accuracy is 0.1 ppm (in a vacuum).

Continued on page 44

Classified Advertising

SYNTELLECT CORPORATION ANNOUNCES VIDEO COURSES ON ARTIFICIAL INTELLIGENCE, EXPERT SYSTEMS AND ROBOTICS. You have had the opportunity of reading Dr. Rajaram's articles in ROBOTICS ENGINEERING. The unique combination of his scholarship, practical experience and outstanding communication skills has made Dr. Rajaram one of the most highly sought lecturers and consultants in the fields of AI, Expert Systems and Robotics. This is now available to you, where you work, through a series of five video courses developed by him exclusively for SYNTELLECT. For more information, write to: SYNTELLECT Corporation, Educational Services Department, PO Box 580057, Nassau Bay, TX 77058. Telephone: (713) 482-6274. EDUCATIONAL AND NONPROFIT INSTITUTIONS SAVE OVER 50%.

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New Products

Continued from page 43.

Repeatability is 0.02 ppm (in a vacuum).

User-friendly features include controllability, simplified servo-loop interfacing, extensive self-testing, self-configuring, and integral power-supply standard.

For more information, contact: Inquiries Manager, Hewlett-Packard Company, 1820 Embarcadero Rd., Palo Alto, CA 94303.

Circle 112

LITERATURE

- *Keeping America At Work: Strategies For Employing The New Technologies.* Contact: Barbara Monteiro, John Wiley & Sons, 605 Third Ave., New York, NY 10158, telephone (212) 850-6497.
- *Synchro Conversion Handbook.* Contact: Marketing Dept., ILC Data Device Corporation, 105 Wilbur Place, Bohemia, NY 11716, telephone (516) 567-5600.
- *1985-86 Semiconductor Equipment and Material Institute's Membership Directory.* Contact: Marge Ryan, SEMI, Dept. 05607, San Francisco, CA 94139, telephone (415) 964-5111.
- *1986 Directory of Corporate Affiliations.* Contact: National Register Publishing Company, 3004 Glenview Rd., Wilmette, IL 60091, telephone (800) 323-4601; in Illinois, (312) 441-2210.
- *Patenting and Marketing Your Invention.* Contact: Helen Bashar, Van Nostrand Reinhold, 115 Fifth Ave., New York, NY 10003, telephone (212) 254-3232.
- Klinger Catalog 584B. Contact: Klinger Scientific Corp., 110-20 Jamaica Ave., Richmond Hill, NY 11418, telephone (718) 846-3700.
- *End of Arm Tooling: Tips and Techniques.* Contact: Science Media, PO Box 910, Boca Raton, FL 33432, telephone (305) 391-0332.
- Airpax Circuit Breaker Handbook and Catalog. Contact: Airpax Corporation, Cambridge Division, Woods Rd., Box 520, Cambridge, MD 21613, telephone (301) 228-4600.

Calendar

Continued from page 4.

21–24. Artificial Intelligence/Knowledge-based Engineering Seminar. Washington, DC. Contact: Conference Manager, U.S. Professional Development Institute, 1620 Elton Rd., Silver Spring, MD 20903, telephone (301) 445-4400. (To be repeated **5–8 May** in Los Angeles, CA; **27–30 May** in New York, NY; **16–19 June** in Austin, TX; and **8–11 July** in Chicago, IL.)

22–24. Quality Expo TIME. O'Hare Expo Center, Rosemont, IL. Contact: Quality Expo TIME, 2400 E. Devon Ave., Suite 205, Des Plaines, IL 60018, telephone (800) 323-5155; in IL, (312) 299-3131.

27–30. Expert Systems. Hyatt Regency, Cambridge, MA. Contact: Continuing Education Institute, 10889 Wilshire Blvd., Los Angeles, CA 90024, telephone (213) 824-9545. (To be repeated **5–7 May** in Monterey, CA.)

28–30. Speech Tech '86. Waldorf-Astoria Hotel, New York, NY. Contact: Stanley Goldstein, Publisher, Media Dimensions, Inc., 42 E. 23rd St., New York, NY 10010, telephone (212) 533-7481/7483.

29–May 1. Motor City Fluid Power Show V/National Conference on Fluid Power. Cobo Hall, Detroit, MI. Contact: G.B. Randall, 4922 Wildwood, Harrison, MI 48625, telephone (517) 539-2745.

MAY

6–8. Control Expo 86. O'Hare Exposition Center, Rosemont, Il. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

6–8. Logistex 86. Cervantes Convention Center, St. Louis, MO. Contact: Logistex 86, 940 Western Ave., Pittsburgh, PA 15233, telephone (412) 323-1808.

12–13. UNIX Operating System Seminar. Dallas, TX. Contact: Conference Manager, U.S. Professional Development Institute, 1620 Elton Rd., Silver Spring, MD 20903, telephone (301) 445-4400. (To be repeated **19–20 May** in Boston, MA; **2–3 June** in Washington, DC; **9–10 June** in San Francisco, CA; **16–17 June** in New York, NY; and **23–24 June** in Chicago, IL.)

13–15. Electro/86 High Technology Electronics Exhibition and Convention. Bayside Exposition Center, World Trade Center, Boston, MA. Contact: J. Fossler, Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045, telephone (213) 772-2965.

14–16. C Programming Seminar. Dallas, TX. Contact: Conference Manager, U.S. Professional Development Institute, 1620 Elton Rd., Silver Spring, MD 20903, telephone (301) 445-4400. (To be repeated **21–23 May** in Boston, MA; **4–6 June** in Washington, DC; **11–13 June** in San Francisco, CA; **18–20 June** in New York, NY; and **25–27 June** in Chicago, IL.)

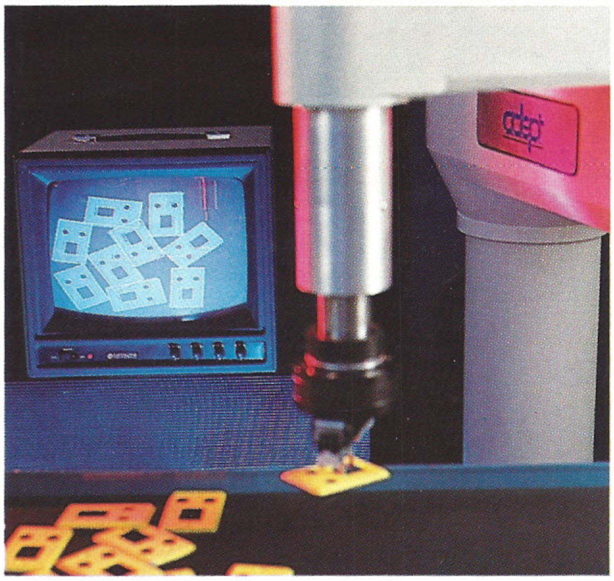
14–16. Fiber Optics Technology for Communications. Contact: Ron Donais, The George Washington University, Washington, DC 20052, telephone (202) 676-8523 or (800) 424-9773.

JUNE

5–6. Second Annual Workshop on Robotics and Expert Systems/ROBEXS'86. Gilruth Center NASA/Johnson Space Center, Houston, TX. Contact: Deborah A. Poor, Instrument Society of America, 67 Alexander Dr., PO Box 12277, Research Triangle Park, NC 27709, telephone (919) 549-8411.

17–18. Robotic End Effectors: Design and Applications. Detroit, MI. Contact: Diane M. Korona, Program Administrator, Special Programs Division, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0039.

Why robot vision doesn't have to slow a robot down.



Most robot vision systems simply aren't good communicators. They load a robot down with more data than it can handle . . . and transmit that data over slow serial or I/O ports. So while they might "see" in real time, they can't make the robot react in real time.

AdeptVision™ can. . . and does.

Real time vision, real time reaction.

AdeptVision communicates with the robot controller quickly because it communicates directly . . . in the same language . . . without any of the integrating hardware and software that slows other systems down and drives installation costs up.

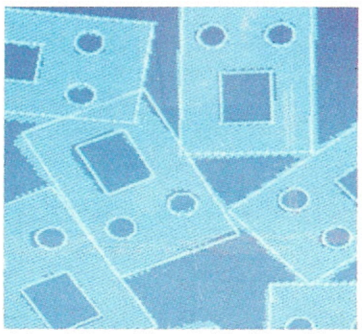
In other words, AdeptVision comes fully integrated with the Adept robot system, and the result is sheer speed. In both its area and moving line versions, AdeptVision identifies and locates up to six parts per second — and communicates the information fast enough to guide the robot's path in real time.

Simplicity plus brainpower.

Most vision systems require special software for each part they handle. And most vision companies don't tell you that. This can burn up several man-months of an expensive programmer's time and delay your start-up significantly.

AdeptVision requires no part-specific software. It's ready to go the day you install it and requires only about 15 minutes of training per part.

What's more, because AdeptVision identifies significant part features instead of the entire part area, it accomplishes more with less raw data. And then turns it into real time robot guidance information with powerful 68000 processors.



AdeptVision™ quickly identifies randomly oriented, touching, or overlapping parts.

Touching and overlapping parts.

Most vision systems can't identify parts the way they're presented in real life: randomly oriented, touching, or even overlapping. AdeptVision can, because its unique algorithms work with part features instead of areas.

This flexible parts presentation ability can save you a fortune in hard tooling costs now . . . and later on when you change product mix or design.

Seeing is believing.

We'd like to show you AdeptVision in action . . . at an Adept-equipped systems integrator near you. Just give us a call, and we'll make the arrangements. In the meantime, we'll mail you all the details. Just contact Adept Technology, Inc., 1212 Bordeaux Drive, Sunnyvale, California 94089. Phone: (408) 747-0111. TELEX: 171942.

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Robots that work.

Circle 32